# นิเวศวิทยาการกินอาหารของปลาตะกรับ *Scatophagus argus*, Linnaeus
# ในบริเวณป่าชายเลนลุ่มน้ำปากพนัง จังหวัดนครศรีธรรมราช

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**ปีการศึกษา 2550**

**FEEDING ECOLOGY OF SPOTTED SCAT *Scatophagus argus*, Linnaeus IN MANGROVE FORESTS PAK PHANANG ESTUARY, NAKHON SI THAMMARAT PROVINCE**

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สุพิชญา วงศ์ชินวิทย์: นิเวศวิทยาการกินอาหารของปลาตะกรับ *Scatophagus argus*, Linnaeus ในบริเวณป่าชายเลนลุ่มน้ำปากพนัง จังหวัดนครศรีธรรมราช (FEEDING ECOLOGY OF SPOTTED SCAT *Scatophagus argus*, Linnaeus IN MANGROVE FORESTS PAK PHANANG ESTUARY, NAKHON SI THAMMARAT PROVINCE) อ.ที่ปรึกษา: รศ. ณิฏฐารัตน์ ปภาวสิทธิ์, อ.ที่ปรึกษาร่วม: รศ.สพ.ญ.ดร. อัจฉริยา ไศละสูต จำนวน 291 หน้า.

การศึกษาครั้งนี้มีวัตถุประสงค์ศึกษาความสำคัญของป่าชายเลนต่อประชาคมปลาตะกรับในแง่เป็นแหล่งอาหาร โดยศึกษารูปแบบลักษณะการกินอาหารและพัฒนาการของระบบทางเดินอาหารรวมทั้งประสิทธิภาพการย่อยและดูดซึมอาหารของปลาตะกรับ เพื่อทราบถึงบทบาทของปลาตะกรับในการถ่ายทอดพลังงานในป่าชายเลน นอกจากนี้ยังทำการศึกษาการแบ่งสรรทรัพยากรในกลุ่มประชากรปลาตะกรับกับปลากระบอกที่มีลักษณะการกินอาหารคล้ายคลึงกัน

ผลการศึกษาพบปลาตะกรับอาศัยป่าชายเลนปลูกบริเวณอ่าวปากพนัง จังหวัดนครศรีธรรมราชอย่างถาวร เป็นทั้งแหล่งอาหาร แหล่งอนุบาล และที่อยู่อาศัย โดยเมื่อป่าชายเลนมีอายุมากขึ้นทำให้ปริมาณอินทรีย์สารในมวลชีวภาพในส่วนต่างๆของพันธุ์ไม้สูงขึ้น และปริมาณสัตว์หน้าดินพบหอยฝาเดียว หนอนตัวกลม และตัวอ่อนแมลงเป็นกลุ่มเด่น ส่วนแพลงก์ตอนพืชกลุ่มไดอะตอมและไซยาโนแบคทีเรียพบเป็นกลุ่มเด่นในบริเวณนี้เช่นเดียวกับแพลงก์ตอนสัตว์กลุ่มเด่นได้แก่ โคพีพอด ตัวอ่อนหอย ตัวอ่อนเพรียง ตัวอ่อนปู โรติเฟอร์ และตัวอ่อนกุ้ง สิ่งมีชีวิตเหล่านี้เป็นแหล่งอาหารที่สำคัญของปลาตะกรับ องค์ประกอบอาหารกลุ่มเด่นที่พบในกระเพาะอาหารของปลาทุกช่วงอายุคือเพนเนตไดอะตอมและสาหร่ายสีเขียวแกมน้ำเงิน จากองค์ประกอบอาหารทั้งหมดที่พบในกระเพาะอาหารแสดงให้เห็นว่าปลาตะกรับจัดอยู่ในกลุ่มที่กินทั้งพืชและสัตว์ ปลาตะกรับแสดงลักษณะการปรับตัวที่ดีมากในการเลือกกินอาหารในสภาพแวดล้อมที่มีการแปรผันสูง ปลาตะกรับมีการเปลี่ยนลักษณะการกินอาหารในแต่ละช่วงอายุ โดยระยะลูกปลาจะหาอาหารกินบริเวณผิวน้ำและกลางน้ำ ระยะวัยรุ่นหาอาหารกินบริเวณกลางน้ำและเริ่มหาอาหารที่บริเวณพื้น ขณะที่ระยะโตเต็มวัยกินอาหารที่บริเวณพื้น นอกจากนี้ปลาตะกรับยังมีการเปลี่ยนชนิดอาหารที่กินตามปริมาณอาหาร โดยไม่เฉพาะเจาะจง โดยมีปริมาณของโปรโตซัว สัตว์ทะเลหน้าดิน และอินทรีย์สารในกระเพาะอาหารมีความแตกต่างกันในแต่ละช่วงอายุ ดังนั้นจากลักษณะการปรับตัวทางด้านการกินอาหารทำให้บทบาทของปลาตะกรับในสายใยอาหารระบบนิเวศป่าชายเลนอ่าวปากพนังอยู่ในลำดับขั้นเดียวกับกลุ่มปลาที่กินสัตว์ทะเลหน้าดิน, กลุ่มปลาที่กินแพลงก์ตอนสัตว์ และกลุ่มปลาที่กินซากอินทรีย์สาร

จากการศึกษาลักษณะทางเนื้อเยื่อวิทยาของระบบทางเดินอาหารของปลาตะกรับ พบลักษณะทางเนื้อเยื่อวิทยาระบบทางเดินอาหารเปลี่ยนแปลงไปตามช่วงอายุ เมื่อปลามีขนาดใหญ่ขึ้น ฟันจะมีขนาดเล็กลง จำนวนของซี่ฟันเพิ่มขึ้น กระเพาะอาหารส่วนกลางเป็นบริเวณที่ทำหน้าที่ย่อยอาหารและมีต่อมขับน้ำย่อยมากที่สุด จำนวนต่อมขับน้ำย่อยเพิ่มขึ้นไปตามช่วงอายุ ไส้ติ่งทำหน้าที่ช่วยผลิตน้ำย่อยย่อยไขมันและดูดซึมอาหาร จำนวนไส้ติ่งเพิ่มขึ้นในแต่ละช่วงอายุ ทำให้อาหารหลายชนิดที่กินถูกย่อยได้มากขึ้น ขณะที่ลำไส้ส่วนต้นเป็นบริเวณที่มีพื้นที่ดูดซึมอาหารสูงสุด และพื้นที่ดูดซึมอาหารเพิ่มขึ้นตามช่วงอายุด้วย บริเวณลำไส้ส่วนต้นมีน้ำย่อยที่สร้างมาจากตับ ตับอ่อน และถุงน้ำดี น้ำย่อยถูกส่งมาทางท่อน้ำดีเพื่อช่วยในการย่อยอาหาร ผลจากการศึกษาสัณฐานวิทยาและลักษณะเนื้อเยื่อวิทยาของระบบทางเดินอาหารแสดงให้เห็นว่าสอดคล้องกับการเปลี่ยนแปลงลักษณะการกินอาหารและอาหารที่เปลี่ยนแปลงในแต่ละช่วงอายุ การเลือกกินอาหารของปลาตะกรับเป็นไปตามหลักเกณฑ์ของ Optimal Foraging Theory ปลาตะกรับแต่ละช่วงอายุเลือกกินชนิดอาหารที่มีปริมาณมาก ขนาดของอาหารเหมาะสมกับความกว้างของช่องปาก ลักษณะของฟันและซี่กรองเหงือก และความยาวของลำไส้ที่เพิ่มขึ้น อาหารที่เลือกกินเมื่อย่อยแล้วได้รับปริมาณโปรตีนและไขมันสูง รวมทั้งพลังงานสุทธิที่ได้รับสูงเช่นเดียวกัน เพื่อสามารถดูดซึมนำไปใช้ได้อย่างมีประสิทธิภาพ การแบ่งสรรทรัพยากรอาหารระหว่างปลาตะกรับและปลากระบอกแสดงความแตกต่างระหว่างลักษณะทางสัณฐานวิทยาของระบบทางเดินอาหารและมีการเปลี่ยนพฤติกรรมการกินอาหารอย่างชัดเจน โดยปลาตะกรับเป็นกลุ่มปลาที่กินทั้งพืชและสัตว์ ขณะที่ปลากระบอกเป็นกลุ่มปลาที่กินพืช ปลาทั้งสองชนิดมีไดอะตอมและอินทรีย์สารเป็นองค์ประกอบอาหารหลักที่ซ้อนทับกัน

จากการศึกษาครั้งนี้แสดงให้เห็นถึงความสำคัญของการปลูกและฟื้นฟูป่าชายเลนในบริเวณอ่าวปากพนังในการเป็นแหล่งอาหารและแหล่งที่อยู่อาศัยของปลาตะกรับ ปลาตะกรับมีการปรับตัวที่ดีมากในการเลือกกินอาหารและทางสรีรวิทยาทำให้สามารถอยู่รอดได้ในสภาพแวดล้อมที่มีการแปรผันสูงในอ่าวปากพนัง เราสามารถใช้ปลาตะกรับเป็นดัชนีที่บ่งชี้ในการติดตามการเปลี่ยนแปลงสภาพป่าชายเลนและสิ่งแวดล้อมได้ ดังนั้นจึงควรมีการส่งเสริมให้เลี้ยงปลาตะกรับเป็นอาชีพเสริมสำหรับชุมชนและปล่อยคืนปลาตะกรับลงสู่อ่าวปากพนังควบคู่กับการปลูกและฟื้นฟูป่าชายเลนเพื่อเพิ่มผลผลิตประมงอย่างยั่งยืน

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SUPICHAYA WONGCHINAWIT: FEEDING ECOLOGY OF SPOTTED SCAT *Scatophagus argus*, Linnaeus IN MANGROVE FORESTS PAK PHANANG ESTUARY, NAKHON SI THAMMARAT PROVINCE. THESIS ADVISOR: ASSOC. PROF. NITTHARATANA PAPHAVASIT, THESIS CO-ADVISOR: ASSOC. PROF. ACHARIYA SAILASUTA D.V.M., Ph.D. 291 pp.

Feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests Pak Phanang Estuary, Nakhon Si Thammarat Province is used as the assessment on the role of mangrove forest as food source for fish. Feeding strategies in different stages in relation to feeding structure morphology, development of alimentary tracts and associated digestive organs and assimilation efficiency are determined. The trophic role of *Scatophagus argus* in mangrove food webs was demonstrated. Niche partitioning in spotted scat, *Scatophagus argus* and adult tade mullet, *Liza planiceps* sharing the same food resources was also demonstrated.

The role of mangrove plantations in Pak Phanang Estuary supported the availability of food source, nursery ground and habitat for spotted scat as true resident species. The study showed the increase in organic detritus in term of forest biomass as the mangrove plantations aged. The gastropods, nematodes and insect larvae also found as dominant benthos. Diatom and cyanobacteria were most dominant microphytoplankton. Zooplankton diversity dominated by copepod, mollusk larvae, cirripedia nauplii, zoea of brachyuran, rotifers and shrimp larvae. These provided rich food sources for spotted scat. Diatoms and cyanobacteria were the most common dietary components in each stage. Spotted scat showed broad diets, being omnivore and opportunistic feeder. Spotted scat showed ontogenetic niche shift with larval stage predominantly fed in the surface water and in water column. Juveniles were the transition stages feeding in the water column and bottom substrates. Adults were adapted to feed on bottom substrates. Protozoa, benthos and detritus showed different ratio in diet of each stage. Due to the flexibility in spotted scat feeding, this fish was classified as secondary consumers in the Pak Phanang mangrove food webs sharing the same trophic levels with zooplankton feeders and benthic feeders.

Histological study of alimentary system of spotted scat revealed the variations according to ages and feeding habits. In large fish, smaller and numerous teeth were found. The fundic portion has gastric glands increasing markedly with ages which secrete gastric juices for digestion. The pyloric caeca appeared to be the important sites for lipid digestion allowing optimized absorption. The villi on the intestinal walls increased markedly in the duodenum as the main absorptive site. The bile duct from the liver and gall bladder together with enzymes from the pancreas are all sent into the duodenum portion. Morphological and histological studies of the alimentary system correlated to the relative importance of components in diets of each stage and ontogenetic niche shift. Spotted scat in each stage showed the feeding ecology following optimal foraging theory. Optimal prey size suitable to mouth gape that maximizes food consumed per unit capture, were choosen. Acquisition of diets also based on the nutritional quality and energy as revealed from the assimilation efficiency study. Niche partitioning between spotted scat and tade mullet were shown by differences in feeding morphology and behavior, alimentary system and seasonal shifts in relative importance of different components in diets. The study confirmed tade mullet were herbivore. Niche overlap in food items, mainly microphytoplankton and detritus, were evidenced in spotted scat and tade mullet diets.

From this study, the role of mangrove reforestation in Pak Phanang Estuary is important in providing food sources and habitats for spotted scat. This fish showed flexibility in term of feeding and physiological tolerances which allow survivals in estuarine environment in Pak Phanang Estuary. This fish is the good indicator for monitoring changes in mangrove and environmental condition. Thus the spotted scat culture should be promoted as supplementary income for coastal communities. Releasing spotted scat fry into the estuary along as a part of the mangrove reforestation program are recommended to sustain the fishery in the area.

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**CONTENTS**


Page

Thai Abstract…………………………………………………………………………….. iv

English Abstract…………………………………………………………………………. v

Acknowledgements………………………………………………………………………. vi

Contents…………………………………………………………………………………... vii

List of Tables……………………………………………………………………………... ix

List of Figures…………………………………………………………………………….. xi

CHAPTER I INTRODUCTION…………………………………………………………. 1

A. General Background and Hypothesis……………………………………...... 1

B. Spotted scat, *Scatophagus argus* as Related to the Mangrove Forest…………. 2

C. Conceptual Framework of Research…………………………………………... 6

D. Description of Study Area……………………………………………………... 13

E. Sampling Period……………………………………………………………….. 16

F. Research Methodology………………………………………………………... 18

G. Objectives……………………………………………………………………… 21

H. Expected Results………………………………………………………………. 21

CHAPTER II IMPORTANCE OF PAK PHANANG MANGROVE FOREST FOR FISH COMMUNITIES..……………………………………………………………... 22

A. Introduction……………………………………………………………………. 22

B. Literature Review……………………………………………………………… 23

C. Materials and Methods………………………………………………………… 30

D. Results and Discussions………………………………………………………. 33

E. Conclusion…………………………………………………………………...... 79

CHAPTER III FEEDING ECOLOGY IN SPOTTED SCAT, *Scatophagus argus*................ 83

A. Introduction……………………………………………………………………. 83

B. Literature Review……………………………………………………………… 84

C. Materials and Methods………………………………………………………… 99

D. Results and Discussions……………………………………………………….. 102

E. Conclusion……………………………………………………………………... 132

Page

CHAPTER IV HISTOLOGICAL ADAPTATIONS IN DIGESTIVE SYSTEM AND FEEDING EFFICIENCY IN SPOTTED SCAT………………………… 134

A. Introduction……………………………………………………………… 134

B. Literature Review……………………………………………………….. 135

C. Materials and Methods…………………………………………………... 144

D. Results and Discussions…………………………………………………. 147

E. Conclusion………………………………………………………………. 183

CHAPTER V NICHE PARTITIONING IN SPOTTED SCAT *Scatophagus argus* AND ADULT TADE MULLET *Liza planiceps* COMMUNITIES………………. 186

A. Introduction……………………………………………………………. 186

B. Literature Review……………………………………………………….. 187

C. Materials and Methods………………………………………………….. 192

D. Results and Discussions…………………………………………………. 194

E. Conclusion………………………………………………………………. 211

CHAPTER VI SYNTHESIS AND RECOMMENDATION……………………………….. 212

A. Research Synopsis… ……………………………………………………… 212

B. Rehabilitation and Management of Spotted Scat, *Scatophagus argus*………. 214

C. Promoting *Scatophagus argus* as Aquaculture Species …………………….. 217

D. Stress Indicators-Living in Stressful Environment………………………….. 218

REFERENCES…………………………………………………………………………... 222

APPENDICES………………………………………………………………………….. 246

APPENDIX I ………………………………………………………………………….. 247

APPENDIX II …………………………………………………………………………. 255

APPENDIX III………………………………………………………………………… 274

APPENDIX IV ………………………………………………………………………... 284

BIOGRAPHY………………………………………………………………………….. 291

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1.1 | Meristic characters of Indo-Pacific *Scatophagus* genera………………………….. | 5 |
| 1.2 | Dissertation content on feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province……………………………………………………………………………….. | 10 |
| 1.3 | Sampling stations and site description in Pak Phanang Estuary, Nakhon Si Thammarat Province……………………………………………………………….. | 14 |
| 1.4 | Environmental parameters between high and low salinity period in Pak Phanang mangrove forests, Nakhon Si Thammarat Province (Mean±SE)………………….... | 16 |
| 2.1 | Feeding types of dominant group in estuarine and mangrove areas in the Gulf of Thailand……………………………………………………………………………….. | 27 |
| 2.2 | Feeding types of dominant group in estuarine and mangrove areas on Andaman coastline………………………………………………………………………….............. | 28 |
| 2.3 | Species lists of fish in various stages in Pak Phanang mangrove forests, Nakhon Si Thammarat Province during May 2004-October 2005 ……………………………. | 35 |
| 2.4 | Habitat utilization in fish communities in Pak Phanang mangrove forests, Nakhon Si Thammarat Province based on different stages found in the mangroves and in comparison with other reports and http://www.fishbase.org/search.php. …............. | 42 |
| 2.5 | Feeding types of fish in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………………………………………………………….. | 54 |
| 2.6 | Environmental parameters between high and low salinity period in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………….. | 55 |
| 2.7 | Pearson Correlation test between environmental parameters and food sources with density of fish during high and low salinity periods…………………………….. | 60 |
| 2.8 | Pearson Correlation test between environmental parameters and food sources with density of spotted scat during high and low salinity periods………………………. | 69 |
| 2.9 | Fishery status in Pak Phanang Estuary during May 2004-October 2005 from the fishery survey……………………………..…………………………………….... | 71 |
| 2.10 | Spotted scat fisheries in Pak Phanang Bay during May 2004-October 2005 from the fishery survey……………………………..………………………………… | 75 |

| Table | | Page |
|---|---|---|
| 3.1 | Comparative measurement on feeding structure morphology of spotted scat…….. | 104 |
| 3.2 | Comparative study on feeding structure morphology of spotted scat……………… | 105 |
| 3.3 | List of prey items identified in larval spotted scat stomachs at different salinity from mangrove forests and index of relative importance (IRI) value……………… | 110 |
| 3.4 | List of prey items identified in juvenile spotted scat stomachs at different salinity from mangrove forests and index of relative importance (IRI) value……………… | 113 |
| 3.5 | List of prey items identified in adult spotted scat stomachs at different salinity from mangrove forests and estuarine waterways and index of relative importance (IRI) value…………………………………………………………………….. | 117 |
| 3.6 | Feeding behavior of spotted scat larvae……………………………………………. | 124 |
| 3.7 | Feeding behavior of juvenile spotted scat ………………………………………... | 125 |
| 3.8 | Feeding behavior of adult spotted scat …………………………………………….. | 126 |
| 3.9 | Feeding preference on microphytoplankton and zooplankton of spotted scat……... | 128 |
| 4.1 | The histological structure of alimentary system in spotted scat (Mean±SE)…….. | 148 |
| 4.2 | Proximate analysis from three stages of spotted scat…………………………..... | 176 |
| 4.3 | Gross energy and apparently digested energy of prey items and feces…………… | 176 |
| 5.1 | Density of prey items of tade mullet, *Liza planiceps* in mangrove forests and estuarine waterways…………………………………………………………….... | 196 |
| 5.2 | List of prey items in tade mullet stomachs at different salinity from mangrove forests and estuarine waterways and index of relative importance (IRI) value…… | 199 |
| 5.3 | Niche overlap and percentage overlap in prey items of spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* in mangrove forests at different salinity…… | 203 |
| 5.4 | Niche overlap and percentage overlap in prey items of spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* in high salinity of estuarine waterways…..... | 204 |
| 5.5 | Comparative study on feeding structure morphology in spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps*………………………………………....... | 260 |
| 6.1 | Summary of parasites observed in the spotted scat………………………………… | 221 |

## LIST OF FIGURES

**Figure** **Page**


1.1 Morphological characters of spotted scat *Scatophagus argus* from this study……... 4

1.2 The head profiles of a female (upper) and male (lower) spotted scat showing the sexual dimorphism which can be used to differentiate between sexes……………... 6

1.3 Conceptual framework research on feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province…………………………………………………………………………... 9

1.4 Study sites at Pak Phanang Estuary, Nakhon Si Thammarat Province……………... 13

1.5 Measurement of average salinity in three mangrove plantations as related to monthly rainfall amount (Royal-initiated Pak Phanang Basin Area Development Project)………………………………………………………………………… 17

2.1 Amount and distribution in each sampling areas of fish larvae in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………... 38

2.2 Amount and distribution in each sampling areas of juveniles in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………... 38

2.3 Amount and distribution in each sampling areas of adults in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………... 39

2.4 Density of microphytoplankton in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………………………………………... 45

2.5 Density of zooplankton >103 micrometer in Pak Phanang mangrove forests, Nakhon Si Thammarat Province………………………………………………… 47

2.6 Density of zooplankton >330 micrometer in Pak Phanang mangrove forests, Nakhon Si Thammarat Province………………………………………………… 48

2.7 Grain size in Pak Phanang mangrove forests, Nakhon Si Thammarat Province…… 49

2.8 Organic matter content (Mean±SE) in Pak Phanang mangrove forests, Nakhon Si Thammarat Province………………………………………………………........ 51

2.9 Total forest biomass in Pak Phanang mangrove forests, Nakhon Si Thammarat Province……………………………………………………………………………... 51

**Figure** **Page**

2.10 Feeding types of fish in Pak Phanang mangrove forests, Nakhon Si Thammarat Province…………………………………………………….......................... 53
2.11 Environmental parameters in each station during collection period in Pak Phanang mangrove forests, Nakhon Si Thammarat Province………………………………... 56
2.12 Distribution pattern of *Scatophagus argus* during high salinity 2004, May 2004 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province…………………. 62
2.13 Distribution pattern of *Scatophagus argus* during low salinity 2004, October 2004 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province………………. 63
2.14 Distribution pattern of *Scatophagus argus* during high salinity 2005, May 2005 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province…………………. 64
2.15 Distribution pattern of *Scatophagus argus* during high salinity 2005, October 2005 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province………………. 65
2.16 Spotted scat fishing ground in Pak Phanang Estuary, Nakhon Si Thammarat Province……………………………………………………………………………... 74
3.1 Feeding structure morphology in herbivorous fish…………………………………. 84
3.2 Feeding structure morphology in plankton feeders…………………………………. 85
3.3 Feeding structure morphology in carnivorous fish…………………………………. 86
3.4 Feeding structure morphology in omnivorous fish…………………………………. 87
3.5 Feeding structure morphology in detritivorous fish………………………………… 87
3.6 The prey size range available to a predator that eats its prey whole………………... 88
3.7 Strategy of preference feeding of fish larvae……………………………………….. 89
3.8 Feeding type according to Holling’s Functional Response…………………………. 90
3.9 Conceptual relations between prey size and mouth size of fish larvae……………... 95
3.10 Experimental design on the experiment on feeding preference in spotted scat…….. 101
3.11 Dietary components in spotted scat in mangrove forests and estuarine waterways in Pak Phanang Estuary, Nakhon Si Thammarat Province…………………………. 107
3.12 Comparative prey items in three spotted scat stages in Pak Phanang mangrove forests……………………………………………………………………………….. 108
3.13 Diet preferences of larval spotted scat in mangrove forests during low salinity (a) and high salinity (b) ………………………………………………………………… 112

**Figure** **Page**


3.14 Diet preferences of juvenile spotted scat in mangrove forests during low salinity (b) and high salinity (a)………………………………………………………….. 115

3.15 Diet preferences of adult spotted scat in mangrove forests during low salinity (a) and high salinity (b)…………………………………………………………… 119

3.16 Diet preferences of adult spotted scat in estuarine waterways during low salinity (a) and high salinity (b)………………………………………………………….. 120

3.17 Carbon and nitrogen (Mean±SE) from stomach content of spotted scat………….. 121

3.18 Carbon and nitrogen ratio from stomach content in three stages of spotted scat..… 122

3.19 Flow chart of behavior types in feeding of spotted scat, *Scatophagus argus*……… 123

3.20 Ontogenetic niche shift in spotted scat in mangrove forests at Pak Phanang Estuary, Nakhon Si Thammarat Province………………………………………….. 130

4.1 Proposed Model of the food web in the mangrove ecosystem……………………... 143

4.2 Line drawing of the alimentary system of spotted scat (A) oriental of the tract in the abdominal cavity, (B) tract extended…………………………………………... 144

4.3 Experimental design on the experiment on digestion efficiency in spotted scat…... 145

4.4 The upper teeth sizes in length (a) and width (b) in three stages of spotted scat (Mean±SE)………………………………………………………………………. 147

4.5 The lower teeth sizes in length (a) and width (b) in three stages of spotted scat (Mean±SE)…………….. ……………………………………………………….. 149

4.6 The thickness of mucosa (a) and muscular (b) layers in esophagus of spotted scat (Mean±SE)………….. ………………………………………………………….. 150

4.7 Teeth in maxilla and mandible of larvae (a,b), juveniles (c,d), adults (e,f) and the magnified teeth structure (g) of spotted scat ……………………………………. 151

4.8 The esophagus of larvae (a), juveniles (b) and adults (c) of spotted scat………….. 152

4.9 The goblet cells in spotted scat respond positively to alcian blue pH 3 stain (a,b)… 153

4.10 The thickness of mucosa (a) and muscular (b) layers in cardiac portion of spotted scat (Mean±SE)…….. ………………………………………………………... 154

4.11 Cardiac portion of larvae stomach (a), juveniles (b) and adults (c) of spotted scat... 155

4.12 Goblet cells and gastric glands in spotted scat……………………………………... 156

4.13 The thickness of mucosa (a) and muscular (b) layers in fundic portion of spotted scat (Mean±SE) ………………………………………………………….……… 157

| Figure | | Page |
|---|---|---|
| 4.14 | Fundic portion of larvae (a), juveniles (b) and adults (c) of spotted scat………….. | 158 |
| 4.15 | Pyloric portion of larvae (a), juvenile (b) and adults(c) of spotted scat …………… | 160 |
| 4.16 | The thickness of mucosa (a) and muscular (a) layers in pyloric portion of spotted scat (Mean±SE)……..………………………………………………………… | 161 |
| 4.17 | Pyloric caeca of larvae (a), juveniles (b) and adults(c) of spotted scat…………….. | 162 |
| 4.18 | The thickness of mucosa (a) and muscular (b) layers in duodenum portion of spotted scat (Mean±SE)…. ………………………………………………………… | 163 |
| 4.19 | The thickness of mucosa (a) and muscular (b) layers in jejunum portion of spotted scat (Mean±SE)……. ……………………………………………………………… | 163 |
| 4.20 | Duodenum portion of larvae (a1:H&E; a2:Alcian Blue), juveniles (b) and adults (c) of spotted scat……………………………………………………................ | 164 |
| 4.21 | Jejunum portion of larvae (a), juveniles (b) and adults (c) of spotted scat………… | 165 |
| 4.22 | The thickness of mucosa (a) and muscular (b) layers in ileum portion of spotted scat (Mean±SE)……………………………………………………………….. | 167 |
| 4.23 | Ileum portion of larvae (a), juveniles (b) and adults (c) of spotted scat……………. | 168 |
| 4.24 | Liver of larvae (a), juveniles and glycogen granules revealed positively to a PAS stain (b1:H&E; b2:PAS) and adults (c) of spotted scat…………………………….. | 170 |
| 4.25 | Pancreas of larvae (a), juveniles (b) and adults (c) of spotted scat……………….... | 172 |
| 4.26 | Acinar cells of pancreas (a) and connective tissue of a large blood vessel in mesentery (b) of juveniles spotted scat …………………………………………… | 173 |
| 4.27 | Gall bladder of larvae (a), juveniles (b) and adults (c) of spotted scat…………….... | 174 |
| 4.28 | The trophic level of spotted scat in mangrove forest food web, Pak Phanang Estuary during low salinity period………………………………………………. | 181 |
| 4.29 | The trophic level of spotted scat in mangrove forest food web, Pak Phanang Estuary during high salinity period……………………………………………… | 182 |
| 5.1 | Morphological characters of *Liza planiceps* in total length 23 cm from this study... | 187 |
| 5.2 | Dietary components in tade mullet, *Liza planiceps* at different salinity in mangrove forests and estuarine waterways in Pak Phanang Estuary, Nakhon Si Thammarat Province…....................................................................................... | 195 |
| 5.3 | Diet preferences of tade mullet in Pak Phanang mangrove forests during low salinity period (a) and high salinity period (b)…………………………………….. | 201 |

**Figure** **Page**

5.4 Diet preferences of tade mullet in estuarine waterways during high salinity period. 202

6.1 The secondary gill lamellae of adult spotted swelling…………………………….. 219

6.2 Hyperplasia and displacement of the respiratory epithelium of spotted scat infected with cysts of *Henneguya* sp. …………………………………………….. 220

6.3 Histological section through the gill of spotted scat with trichodinid infestation….. 221

# CHAPTER I

# INTRODUCTION

## A. General Background and Hypothesis

Spotted scat, *Scatophagus argus*, is one of the economically value fish in the mangrove forests of Pak Phanang Estuary, Nakhon Si Thammarat Province. This fish is commonly found along the coastline, mud flats, estuarine area and sometimes carried up the river by tides. Several studies on mangrove fish indicated that spotted scat utilized the mangrove area as nursery and feeding grounds. Spotted scat feed in the mangrove area due to high diversity and abundance of food sources (Monkolprasit, 1983; Tongnunui, 1997; Vitheesawat, 1999; Somkleeb *et al*., 2001; Paphavasit *et al*., 2004). However, the distribution of spotted scat in different stages in the mangrove area and in the Pak Phanang Estuary has not been studied. Investigations on the life history and habitats of spotted scat in relation to the mangrove forest are also needed. Moreover the studies on the feeding of spotted scat were not conclusive on the role of this fish in the mangrove food webs. It is yet to be determine whether this fish is herbivore, detritivore or omnivore (Arrunyagasemsuke, 1975; Sontirat, 1982; Barry and Fast, 1988; UNDP/UNESCO, 1991; Monkolprasit, 1994; Paphavasit *et al*., 2004). The study on the feeding ecology of spotted scat is important in determining the roles of mangrove forests as food sources for this fish. Several studies revealed that spotted scat larvae were the filter feeders, feeding mainly on microphytoplankton (Barry and Fast, 1988). In contrast, other studies indicated that the larvae as well as juveniles were omnivore feeding on zooplankton, benthos and detritus (Boonruang *et al*., 1994; Vitheesawat, 1999; Musikasung *et al*., 2006). Adults were reported as carnivore/detritivore (Monkolprasit, 1994; Somkleeb *et al*., 2001; Paphavasit *et al*., 2004). The study is also aimed at feeding strategies in different stages of spotted scat in relation to feeding structure morphology, development of digestive tracts and associated digestive organs and assimilation efficiency. These developments allow this fish to feed on diverse food sources leading to ontogenetic shift in spotted scat. Moreover, the detailed study on the feeding behavior and preferences of this spotted scat would help to determine whether this fish was “Specialist” dependent on particular food sources or “Generalist” feeding on various food sources and being trophic adaptability “Opportunistic feeder”. From these results, the importance of mangrove forests as food sources and the roles of spotted scat in the mangrove food webs are able to be concluded.

Apart from the study on feeding ecology, histological study of digestive system in spotted scat and feeding efficiency are necessary. These will provide in depth information to determine whether the feeding ecology in spotted scat follows the optimal foraging theory (Pyke, 1984 as cited by Gerking, 1994). This theory attempts to explain how the fish choose between alternative sources of food by weighing the benefits and costs of capturing one possible choice over the other. Many fish are flexible in their choice of foods, responding to changes in the availability or profitability of potential prey. Such flexibility confers important advantage in terms of both survival and mobility in estuaries.

Spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* are the two co-occuring fish in Pak Phanang Estuary, Nakhon Si Thammarat Province (Somkleeb *et al*., 2001; Paphavasit *et al*., 2004). These fish utilize the mangrove forests and estuarine waterways as feeding grounds. Niche partitioning in fish sharing the same feeding grounds may be the alternative process in reducing competition for the same resources. It also allows the two or more species to exploit the food supply to their fullest extent. Niche partitioning may result in different feeding types, different components of diets utilized or different food sources in the same habitats. Differences in feeding structure morphology and time of feeding may also be the outcome of niche partitioning (Tammongkut, 1984; Boonruang *et al*., 1994; Satapoomin and Poovachiranon, 1997; Paphavasit *et al*., 2000). However, when food partitioning is detected, diet overlap is also customary. The objectives of this study are to assess the diets of these two occurring fish by stomach content analysis and determine the niche overlap in term of food sources. Niche partitioning between spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* is demonstrated.

## B. Spotted Scat, *Scatophagus argus* as Related to the Mangrove Forest

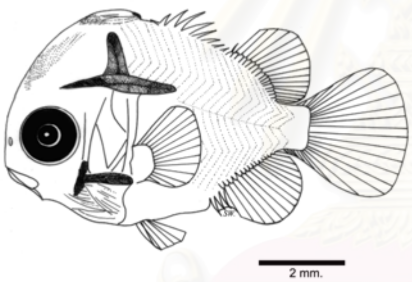


Spotted scat are distributed both on the coastline in the mangrove fringes on the Gulf of Thailand and Andaman Sea. The fish is inhabited in small creeks and waterways where the forest is flooded by high tides. The fish larvae would have the complete access to the intertidal mangrove zone during high tides. This will allow more feeding time and wider dispersal of young fish through the mangrove forests while adult fish migrated to spawn in mangrove areas (Janekarn, 1993; Tongnunui *et al*., 2002). In addition, these fish also distributed on mudflat, coastal areas and estuary. This finding is in consistent with Vatanachai (1979a), Chamchang (1991) and Chayakul (1996) reporting several schools of spotted scat in brackish water and coastal area, mainly during May to October. Moreover, spotted scat migrated to rivers and creeks during high tides (Aiemsomboon *et al*., 1997). According to UNDP/UNESCO (1991), the post larvae were found small creeks during low tides whereas adults were found during neap tides and spring tides in Klong Ngao, Ranong Province in dry and wet seasons. Paphavasit *et al*. (2004) studied fish communities in mangrove plantations in Pak Phanang Estuary, Nakhon Si Thammarat and recorded that the larvae and juveniles of *Scatophagus argus* were found in mudflats while the adults were found in the mangrove plantations of different age and sometimes in stagnant water with shelters. Therefore, the fish in the family Scatophagidae was classified as partial residents, which associated with the mangrove forests as spawning, nursery and feeding grounds (Monkolprasit, 1983; Tongnunui, 1997; Vitheesawat, 1999; Chaves and Bouchereau, 2000; Somkleeb *et al*., 2001; Paphavasit *et al*., 2004; Dorenbosch *et al*., 2004). Classification of spotted scat, *Scatophagus argus* follows Carpenter and Niem (2001)

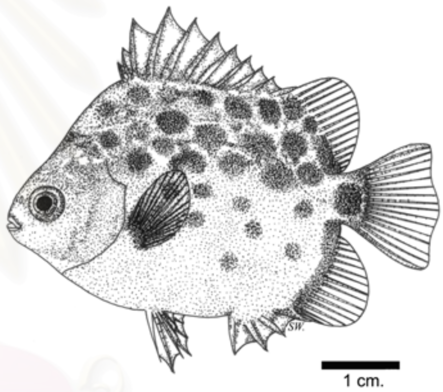
Phylum Chordata
  Subphylum Vertebrata
    Class Actinopterygii
      Subclass Neopterigii
        Division Teleostei
          Order Perciformes
            Family Scatophagidae
              Genus *Scatophagus* Cuvier & Valenciennes
                Species *Scatophagus argus* (Linnaeus) (Spotted scat)

**1. Larval Morphology**

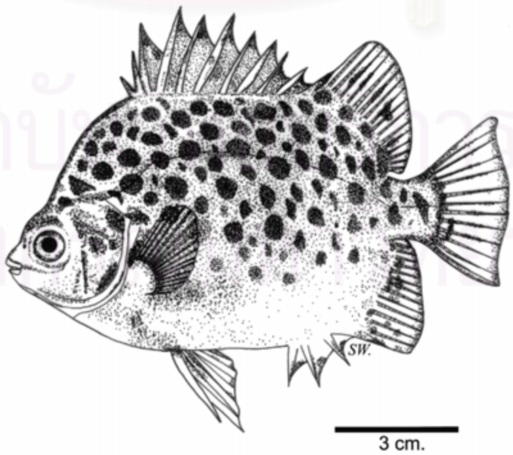
Diagnostic characters: Initially larvae are moderate depth and ovate in cross section but quickly become deeper and more compressed and are deep bodied by 2.6 mm. There are 23 myomeres (pre-anal myomere 12-15+ post-anal myomere 8-11) as in Table 1.1 and Figure 1.1. The triangular gut reaches 56 to 70% body length. However in postflexion larvae, it may be enlarged and lie over the entire gut. Large head is initially very deep and rounded with an almost vertical profile that slowly becomes less steep as the larvae become increasingly deep-bodied. Snout is blunt and often uneven in profile. Mouth is initially moderate and reaches the anterior margin of the pupil, small nostrils is formed and does not reach to the anterior margin of the eye. Small, villifrom teeth are present on both jaws by the commencement of flexion. Large to moderate round eyes. Head spination is remarkably developed and unique. It is well developed even in smallest specimen with an elaborate series of blunt, broad spines and elevated ridges from the frontal (supraocular region), pterotic, posttemporal and preopercle. A heavy, medial, bony process from the supraoccipital that merges with an inflated frontal shell also present. Many of the ridges are ornamented marginally with very fine serrations. In late preflexion larvae, a small complex of spines and ridges develops in the infraorbital region and a ridge extends dorsally from the posttemporal spine. By the time the flexion is completed, the posttemporal ridge also has a granulate pad dorsally. The pelvic fins form early with four rays are present in our smallest specimen. All pelvic elements are present when the flexion completed. The base of the pelvic fin is initially in line with the pectoral-fin base, but the former moves posteriorly, beginning during the flexion stage and comes to rest markedly posterior to the pectoral base. Pigmentation in spotted scat larvae varies from moderate to heavy, depending on the stage of development. All have pigments on the forehead, dorsal surface of the gut and gas bladder, and the ventral midline of the tail. The pelvic fin is heavily pigmented. In addition, pigment commonly occurs on the opercle and the tip of the lower jaw. After the flexion, pigments gradually spread to cover the entire body until the juvenile pattern is attained (Leis and Carson-Ewart, 2000).




Fish larvae in total length 1.0 cm.




Juvenile in total length 5.5 cm.




Adult in total length 12.8 cm.

Figure 1.1 Morphological characters of spotted scat *Scatophagus argus* from this study

Table 1.1 Meristic characters of Indo-Pacific *Scatophagus* genera (Leis and Carson-Ewart, 2000)

| Scatophagidae | Dorsal fin | | Anal fin | | Pectoral fin | Pelvic fin | | Caudal fin | Vertebrae | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. spine | No. soft ray | No. spine | No. soft ray | No. soft ray | No. spine | No. soft ray | No. soft ray | pre-anal myomere | post-anal myomere |
| *Scatophagus* | X-XI | 15-18 | IV | 13-15 | 16-18 | I | 5 | 16 | 10 | 13 |

**2. Juvenile and Adult Morphology**

Diagnostic characters: Spotted scat have compressed and deep bodies covered by small ctenoid scales which extend onto the soft tissue at the bases of the median fins. Head scaly, without spines. Preopercle margin not serrated. Dorsal profile of head slightly concaves to straight in juveniles, distinctly concave above the eyes in adult. Parietals absent. Eyes moderately large. Snout rounded. Mouth small, horizontal, not protractile. Teeth villifrom in several rows on jaws. Maxilla covered by preorbital bone when mouth closed. Pelvic axillary process present. Dorsal head profile steep. Dorsal fin with XI or XII spines and 16 to 18 soft rays; first dorsal-fin spine procumbent; a deep notch between spinous and soft parts of dorsal fin. Anal fin with IV spines and 13 to 16 soft rays. Pectoral fins short and rounded. Pelvic fins with 1 spine with 16 or 17 rays. Pelvic fins with I spine and 5 soft rays. Caudal fin rounded in juveniles, truncate to slightly double emarginate in adults, with 14 branched rays. Vertebrate 23 (pre-anal vertebrate 10 + post-anal vertebrate 13) (Table 1.1). Lateral line distinct, running about parallel to dorsal profile. Gill membranes united and forming a narrow fold across the isthmus. Branchiostegal rays 6. Swim bladder present and simple. Color body greenish or silvery with black spots or bars; juveniles and adults of the same species may have very different color patterns. A few large roundish blotches, about size of eye, or with about 5 or 6 broad, dark, vertical bars (Carpenter and Niem, 2001). Morphological characters of juvenile and adult spotted scat from this study showed in Figure 1.1.

In this study, spotted scat are classified into 3 groups namely: fish larvae in total length 1-2 cm, juveniles in total length 2.1-8 cm and adults in total length more than 8 cm.

**3. Sexual Dimorphism**

The sexes can be differentiated by head shape. The head profile of the female ascends at a relatively constant slope, whereas in the male, there is an obvious curvature of the head above the eye which is absent in female. This difference is more prominent in larger animals, but is noticeable in fish as small as 100 g. Other external features which aid in differentiating between the sexes are: 1. male tend to have more weight than female of equal length at lengths greater than

20 cm; and 2. females, greater than 14 cm, often have a light or olive-green color compared to males, which tend to have a darker color (Figure 1.2).

Figure 1.2 The head profiles of a female (upper) and male (lower) spotted scat showing the sexual dimorphism which can be used to differentiate between sexes (Barry and Fast, 1988).

## C. Conceptual Framework of Research

Spotted scat, *Scatophagus argus*, is one of the economically value fish in the mangrove forests of Pak Phanang Estuary, Nakhon Si Thammarat Province. Several studies on fish of mangrove forests indicated that spotted scat utilized the mangrove area for nursery and feeding grounds. These fish feed in the mangrove area due to high diversity and abundance of food sources. The distribution of spotted scat in different stages in the mangrove area and in the Pak Phanang Estuary has not been studied. Investigations on the life history and habitats of spotted scat in relation to the mangrove forest are also needed. Moreover, the studies on the feeding of spotted scat were not conclusive on the role of these fish in the mangrove food webs. Spotted scat in the mangrove forests in Phangnga and Surat Thani Provinces were mainly of omnivorous fish (Monkolprasit, 1994), whereas spotted scat collected from Tha-Chin mangrove estuary, Samut Sakhon Province were detritivores (Vitheesawat, 1999). In Pak Phanang mangrove plantations found spotted scat were carnivore/detritivore (Paphavasit *et al*., 2004).

Pak Phanang Bay system is one of the richest and most diversed in term of fishery resources. Previously the estuary was lined with rich dense mangrove forests due to mangrove reforestation programs launched by the Royal Forest Department. These mangrove forests served as nursery grounds, permanent habitats and breeding grounds as well as feeding grounds for fishery resources. Unplanned urban expansion and intensive shrimp farming in the Pak Phanang watershed in the past 25 years have resulted in the deteriorating environmental quality and degraded mangrove forests. Conflicts of interest in land use and saline water intrusion have led to the Royal-initiated Pak Phanang Basin Area Development Project, Nakhon Si Thammarat Province. His Majesty King Bhumibol suggested building a regulator with appurtenant structure in the area of Pak Phanang river mouth in order to prevent the intrusion of saline water and to retain freshwater for agriculture and consumption. Digging of drainage canals discharging from the river was also envisaged to reduce the flood problem. The project has commenced in 1983. The dam was first operated in 1999. Prior to the dam construction, circulation and dispersion in the bay fluctuated in response to tides, river input and meteorological factors. The operation of the dam has disrupted the circulation and water exchange processes. Water quality is also affected in term of salinity changes and nutrient loadings. These environmental changes would have impact on the fishery resources. However with the mangrove reforestation programs keeping paces with the environmental changes in the Pak Phanang Bay, it is important to determine whether the mangrove restoration in the area served as the reestablishment of habitats and compensation for ecosystem services that have been or would otherwise be lost as suggested by Forest (1995). Thus, this study selected spotted scat, *Scatophagus argus* as the indicator species to determine the importance of mangrove forests as food sources for fish communities. In depth study on the feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province was planned as in Figure 1.3 and divided into 4 parts namely:

1. Importance of mangrove forests as food sources for spotted scat, *Scatophagus argus* communities

Several studies on fish of mangrove forests including spotted scat indicated that these fish utilized the mangrove area for habitat, nursery and feeding grounds. This study focus on the assessment on the role of mangrove reforestation utilized as habitat and food sources by fish communities in Pak Phanang Estuary. Distribution and abundances of fish communities as related to environmental parameters is determined. *Scatophagus argus* is selected as the indicator species. The dependency of the spotted scat throughout their life history on the mangrove forests as food sources was determined.

2. Feeding ecology in spotted scat, *Scatophagus argus*

Most fish feed according to Optimal foraging theory assumes that food is chosen to maximize the profitability to the forager in relation to feeding structure morphology. Moreover, food density and diversity play the important roles in choosing among prey types. Mangrove forests provide the diverse food sources for fish. These food sources varied according to seasonal, tidal and temporal variations. Therefore, the feeding strategies in different stages of spotted scat in relation to feeding structure morphology and diverse food sources in Pak Phanang Estuary are determined. These developments allow the fish to feed on more diverse food sources leading to niche shift in different stages of spotted scat. Feeding behavior and preference are also investigated. The detailed study on the feeding behavior and preferences of these spotted scat would help to determine whether these fish were "Specialists" "Generalist" or being trophic adaptability "Opportunistic feeder".

3. Histological adaptations in digestive system and feeding efficiency in spotted scat

Spotted scat are the most common fish in Pak Phanang Estuary utilizing different food sources in the mangrove forests. Monkolprasit (1994) and Wongchinvit *et al*. (2006) have described spotted scat as omnivorous fish. Thus, this study aim to elucidate the relationship of histological adaptations in digestive system as related to feeding ecology. The histological studies of the digestive system in each stage of fish are determined. This will provide a better understanding of the relationships of structure and functions in the digestive system of *Scatophagus argus* to their feeding adaptation. The assimilation efficiency of different food sources in spotted scat provides the comparative measure of the nutritional quality of the food items and their suitability as food for fish. The feeding efficiency study in spotted scat is necessary to be conclusive whether the feeding ecology in this fish follows the optimal foraging theory. The role of spotted scat in trophic level in mangrove food web was concluded.

4. Niche partitioning in spotted scat *Scatophagus argus* and adult tade mullet *Liza planiceps*

Spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* inhabit the Pak Phanang mangrove forests and have similar feeding type. Niche partitioning in fish sharing the same feeding grounds may be the alternative process to reduce competition for the same resources. Niche partitioning may result in different feeding types, different components of diets utilized or different food sources in the same habitats whether in the pelagic or benthic origins. Differences in feeding structure morphology and time of feeding may also be the outcomes of niche partitioning. The objectives of this study are to assess the diets of these two occurring fish from stomach content analyses and determine the niche overlap in term of food sources. Niche partitioning between spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* is demonstrated.

The content of the dissertation on feeding ecology of spotted scat, *Scatophagus argus*, Linnaeus, in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province is outlined as in Table 1.2.

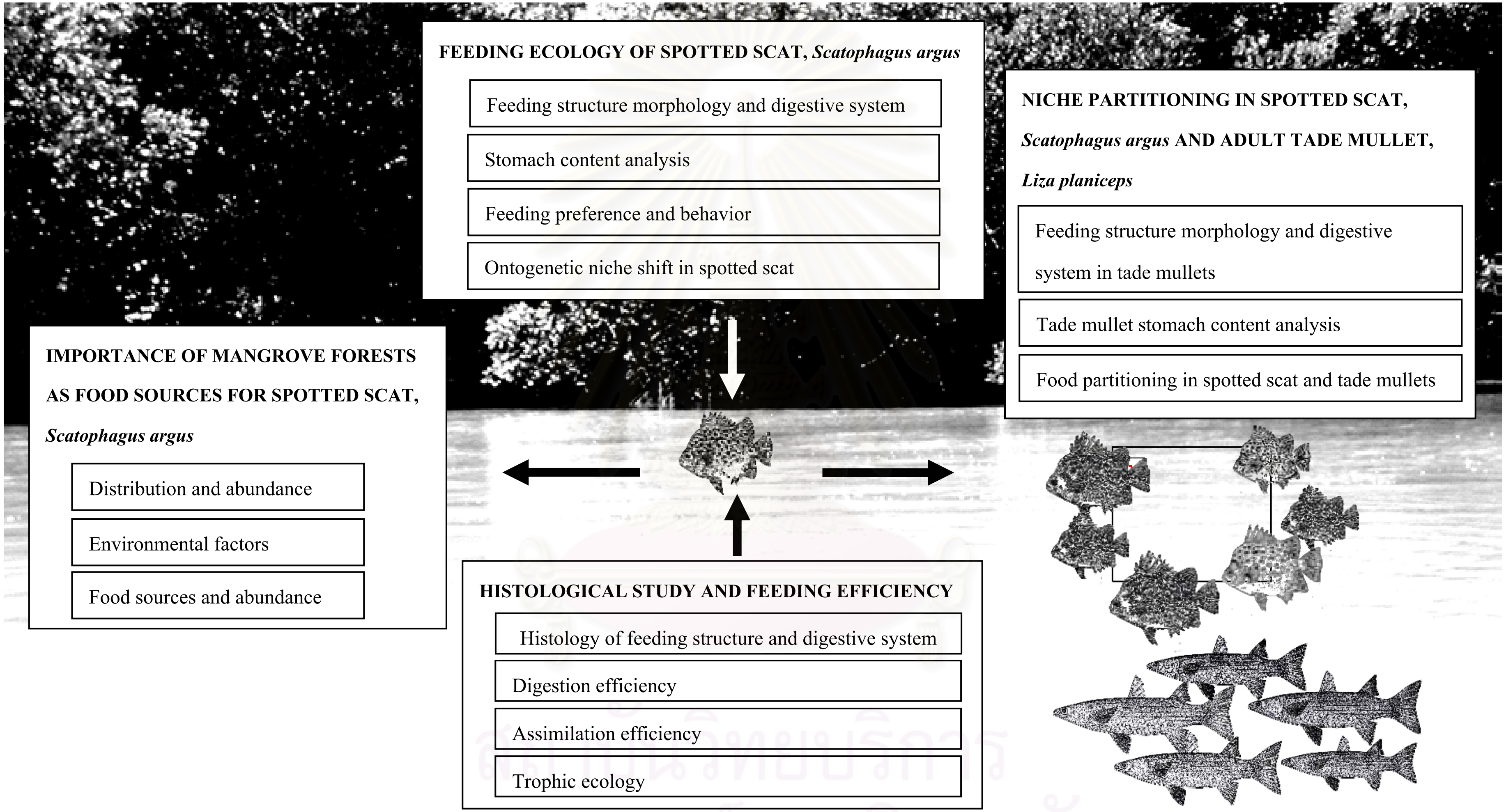



Figure 1.3 Conceptual framework research on feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province

Table 1.2 Dissertation content on feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests, Pak Phanang Estuary, Nakhon Si Thammarat Province

| **Chapter** | **Content** |
|---|---|
| I: INTRODUCTION | A. General Background and Hypothesis<br>B. Spotted scat, *Scatophagus argus* as Related to the Mangrove Forest<br>C. Conceptual Framework of Research<br>D. Description of Study Area<br>E. Sampling Period<br>F. Research Methodology<br>G. Objectives<br>H. Expected Results |
| II: IMPORTANCE OF PAK PHANANG MANGROVE FOREST FOR FISH COMMUNITIES | A. Introduction<br>B. Literature Review<br>1. Importance of Mangrove Forests for Fish Communities<br>2. Mangrove Forests as Food Sources<br>C. Materials and Methods<br>1. Quantitative Study of Fish Communities<br>2. Food Sources in Mangrove Forest<br>3. Environmental Factors<br>4. Data Analyses<br>5. Spotted Scat Fishery Survey in Pak Phanang Estuary<br>D. Results and Discussions<br>1. Assessment on the Role of Mangrove Plantations on Fish Communities in Pak Phanang Estuary<br>2. Abundance and Distribution of *Scatophagus argus* in Pak Phanang Estuary<br>E. Conclusion<br>1. State of Mangrove Dependency in Fish Communities Related to Food Sources<br>2. Environmental Quality as the Main Factors Controlling Habitat Utilization |

Table 1.2 (Continued)

| **Chapter** | **Content** |
| --- | --- |
| III: FEEDING ECOLOGY IN SPOTTED SCAT, *Scatophagus argus* | A. Introduction<br>B. Literature Review<br>1. Morphological Adaptation for Feeding in Fish<br>2. Prey Selection Based on Optimal Foraging Theory<br>3. Niche Shift<br>4. Feeding in Various Stages in Fish<br>5. Feeding Behavior and Preference<br>C. Materials and Methods<br>1. Morphological Study<br>2. Stomach Content Analysis<br>3. Feeding Behavior Preference<br>D. Results and Discussions<br>1. Morphological Adaptations for Feeding in Spotted Scat<br>2. Stomach Content Analysis<br>3. Feeding Behavior and Preference as Related to Morphological Adaptation<br>4. Ontogenetic Niche Shift in Spotted Scat<br>5. Feeding in Spotted Scat Following the Optimal Foraging Theory<br>E. Conclusion |
| IV: HISTOLOGICAL ADAPTATIONS IN DIGESTIVE SYSTEM AND FEEDING EFFICIENCY IN SPOTTED SCAT | A. Introduction<br>B. Literature Review<br>1. Histology of Feeding Structure and Digestive System in Fish with Emphasis on Omnivorous Fish<br>2. Digestion Efficiency<br>3. Trophic Role of Fish in Mangrove Food Webs<br>C. Materials and Methods<br>1. Histology of Feeding Structure and Digestive system<br>2. Digestion Efficiency in Different Stages of Spotted Scat<br>D. Results and Discussions<br>1. Histology of Feeding Structure and Digestive System Related to Types of Food and Feeding Behavior<br>2. Digestion Efficiency<br>3. Optimal Foraging Theory in Spotted Scat as Related to Energy/Assimilation Efficiency.<br>4. Trophic Role of Spotted Scat in Mangrove Food Webs<br>E. Conclusion<br>1. Histological Adaptation in Spotted Scat as Related to Food Spectra and Feeding Behavior<br>2. Feeding in Spotted Scat Following Optimal Foraging Theory in Term of Assimilation<br>3. Trophic Ecology |

Table 1.2 (Continued)

| Chapter | Content |
|---|---|
| V: NICHE PARTITIONING IN SPOTTED SCAT *Scatophagus argus* AND ADULT TADE MULLET *Liza planiceps* | A. Introduction<br>B. Literature Review<br>1. Distribution of Two Co-Occurring Species in Pak Phanang Mangrove Forests<br>2. Feeding Types in Adult Mullet<br>3. Niche Partitioning and Niche Overlap<br>C. Materials and Methods<br>1. Stomach Content Analysis in Spotted Scat and Tade Mullet<br>2. Niche Partitioning in Spotted Scat and Tade mullet<br>D. Results and Discussions<br>1. Feeding Types and Dietary Components in Spotted Scat<br>2. Feeding Types and Dietary Components in Tade Mullet<br>3. Degree of Niche Overlap<br>4. Comparative Study of Feeding Structure Morphology<br>E. Conclusion |
| VI: SYNTHESIS AND RECOMMENDATION | A. Research Synopsis<br>B. Rehabilitation and Management of Spotted Scat, *Scatophagus argus*<br>C. Promoting *Scatophagus argus* as Aquaculture Species<br>D. Stress Indicators-Living in Stressful Environment |

## D. Description of Study Area

Pak Phanang Bay is located at Latitude 8°22'-8°29'N and Longitude 100°04'-l00°l5'E in Pak Phanang District, Nakhon Si Thammarat Province. The outer eastern seaboard of the Bay is a sandy beach that stretches along Laem Talumpuk. The inner and western part of the bay is lined by mangrove forests of approximately 30,000 rai. Pak Phanang Bay is a shallow tidal flat of muddy bottom, elongated basin, approximately 14 km long and widening from 3 km at the mouth of the Pak Phanang River to nearly 10 km at the entrance to the bay. The sampling stations are located as shown in Figure 1.4 and Table 1.3

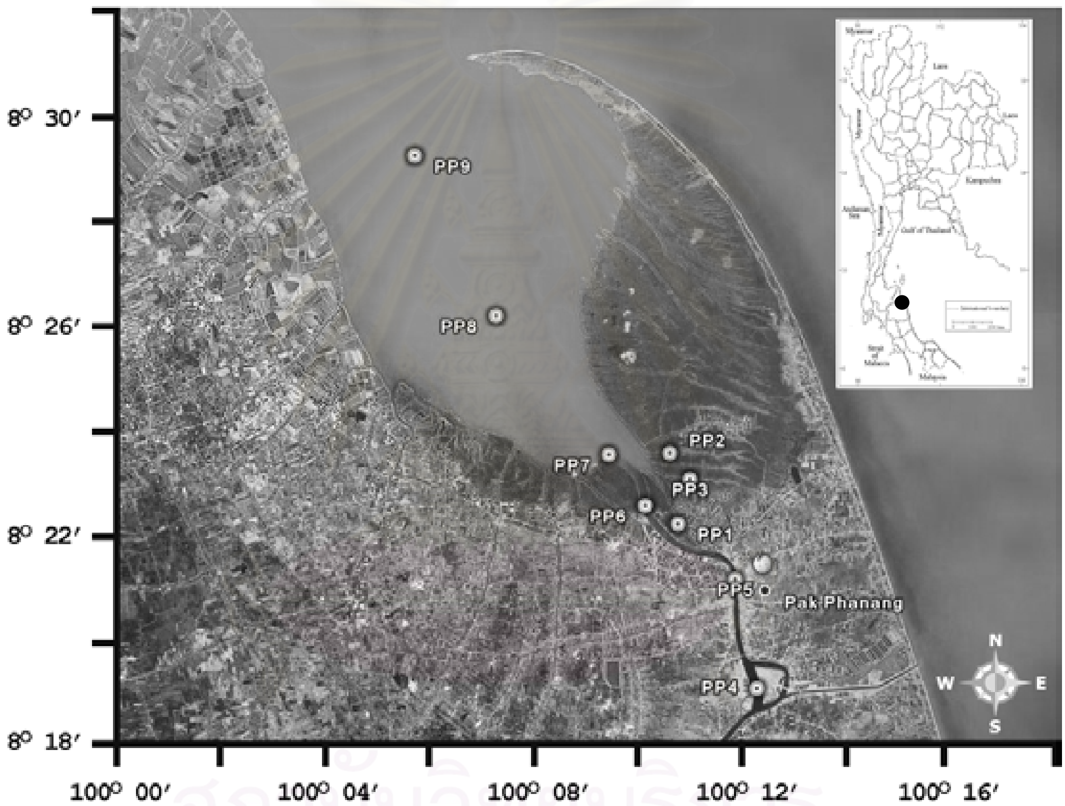



Figure 1.4 Study sites at Pak Phanang Estuary, Nakhon Si Thammarat Province

Table 1.3 Sampling stations and site description in Pak Phanang Estuary, Nakhon Si Thammarat Province

| Station | North | East | Site Description |
|---|---|---|---|
| PP1 | 08°22'04.1" | 100°11'01.8" | Mangrove plantation in the year 1967 (Klong Bang Hua Koo), during this study the mangrove plantation was 37 year olds. *Rhizophora mucronata* and *R. apiculata* were dominant species. The mangrove floor was hard mud bottom. The mangrove floor was flooded only during spring tide. *Nypa fruticans* communities were found scattered in the area as well as *Acrostichum aureum*, *Derris trifoliate* and *Acanthus* spp. Seedlings *Bruguiera sexangula* and *Xylocarpus moluccensis* were found in the area. The average density of trees recorded in 2004 was 161 stem/rai. The average tree diameter and height were 17.40 cm. and 17.12 m respectively (Terathanatorn *et al*., 2007). |
| PP2 | 08°23'14.2" | 100°11'02.1" | Mangrove plantation in the year 1977 (Klong Bang Luk), during this study the mangrove plantation was 27 year olds. *Rhizophora mucronata* and *R. apiculata* were dominant species. The sediment was soft mud bottom and always under the tidal influence. During high tide, the mangrove floor was flooded. High litter falls with sulfide odor covered the mangrove floor. Mangrove plantation nearly reaches the climax stage. Dead large trees still standing mixed with large *Avicennia* trees. Most *Rhizophora* with small tree canopy and few branches. The average tree density in 2004 was 270 stem/rai. The higher tree diameter and height recorded as compared to station PP1 of 19.75 cm and 19.05 m respectively. Seedlings of *Bruguiera sexangula* and *Xylocarpus granatum* can be found in the interspaces. *Sonneratia* spp. and *Nypa* communities also found at along the mangrove fringes (Terathanatorn *et al*., 2007). |

Table 1.3 (Continued)

| Station | North | East | Site Description |
|---|---|---|---|
| PP3 | 08°23'44.7" | 100°10'39.0" | Mangrove plantation in year 1987 (Klong Gong Kong), the mangrove plantation aged 17 year olds in this study. *Rhizophora mucronata*, *R. apiculata* were dominant plants. The soft sediment bottom has high litter falls covered with sulfide odor. Due to high competition, the *Rhizophora* trees were often small in canopy and with some dead trees standing *Avicennia* sp. were found among the interspaces. The average tree density was 225 stem/rai in 2004. Numerous seedling recorded at 197 seeding/rai (Terathanatorn *et al*., 2007). |
| PP4 | 08°19'9.44" | 100°12'17.3" | Pak Phanang River, in front of Uthokvibhajaprasid Regulator far from mouth of bay 3 km |
| PP5 | 08°21'13.97" | 100°11'52.42" | Pak Phanang River in front of the District Office of Amphur Pak Phanang |
| PP6 | 08°22'37.92" | 100°10'9.15" | Western coastline of Pak Phanang Bay near fishing pier |
| PP7 | 08°23'36.10" | 100°9'27.40" | Along the channel of Pak Phanang Bay between buoy No.16 and No.17 |
| PP8 | 08°26'14.3" | 100°7'17.90" | Along the channel of Pak Phanang Bay at buoy No.15 |
| PP9 | 08°29'16.7" | 100°5'44.5" | Klong Pak Nakhon connecting to the Bay |

## E. Sampling Period

The samples were collected in May and October in two consecutive years 2004 and 2005. Prior to the Royal-initiated Pak Phanang Basin Area Development Project commenced, Pak Phanang Estuary has two distinct seasons: wet season from October to January and dry season from March to August. However after the dam was fully operated in 1999, the salinity variations were under the influence of the operation of the dam and runoff due to rainfalls. Measurement of average salinity in three mangrove plantations in relation to monthly rainfall amount (Royal-initiated Pak Phanang Basin Area Development Project) was showed in Figure 1.5. Thus the salinity observed during these samplings in two consecutive years were quite different. Therefore, this study, the environmental parameters are summarized as the period of low salinity and high salinity (Table 1.4).

Table 1.4 Environmental parameters between high and low salinity periods in Pak Phanang mangrove forests, Nakhon Si Thammarat Province (Mean±SE)

| **Environmental parameters** | **Low salinity** (October 2004) | **High salinity** (May 2004, 2005 and October 2005) |
|---|---|---|
| Salinity (psu) | 3.78±0.97 | 27.62±1.08 |
| Temperature ($^{o}$C) | 28.45±0.45 | 29.81±0.24 |
| Dissolved Oxygen (mg./l) | 2.27±0.40 | 4.61±0.35 |
| pH | 7.03±0.03 | 7.44±0.11 |
| Transparency (m.) | 0.26±0.03 | 0.31±0.03 |
| Water depth (m.) | 1.13±0.18 | 1.55±0.37 |

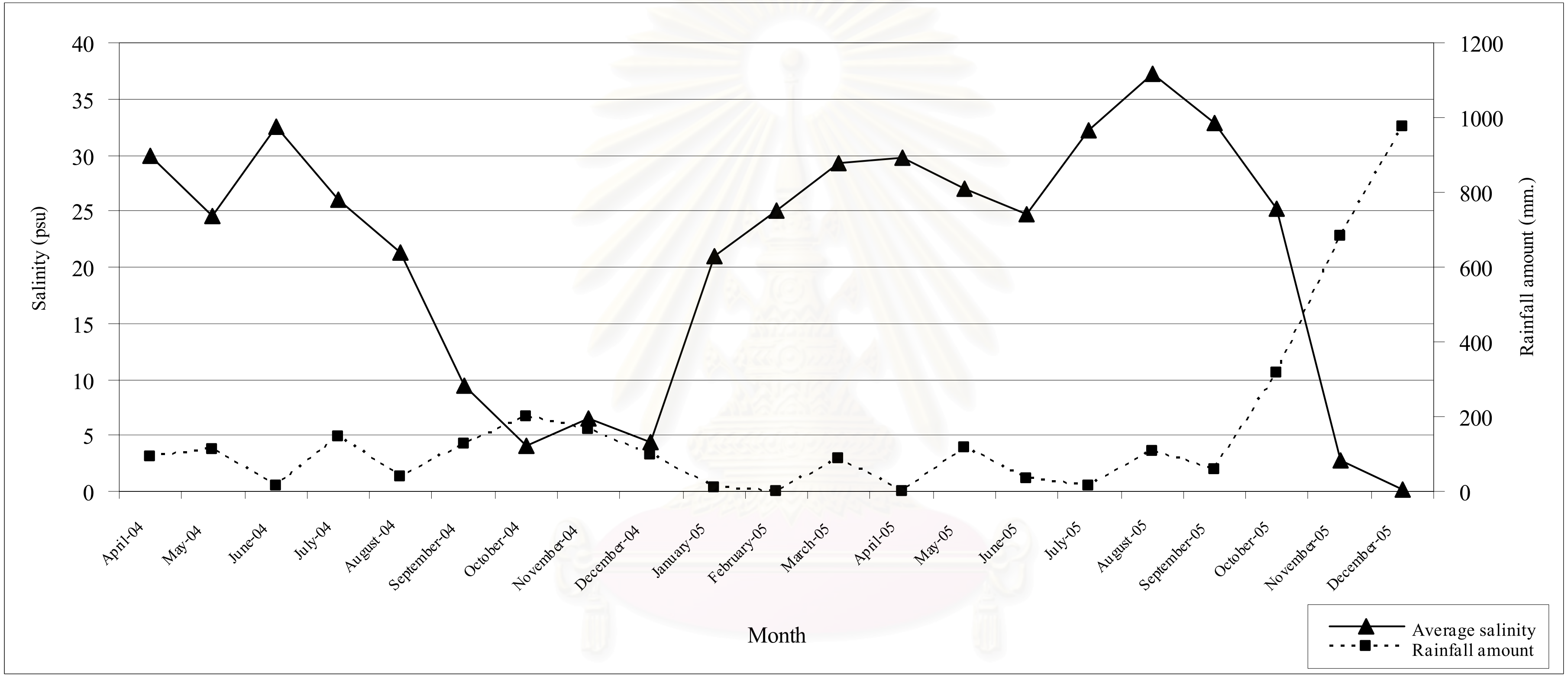



Figure 1.5 Measurement of average salinity in three mangrove plantations as related to monthly rainfall amount

(Royal-initiated Pak Phanang Basin Area Development Project)

## F. Research Methodology

| Research Attributes | Methodology |
|---|---|
| **Importance of Mangrove Forests as Food Sources for Fish Communities** | |
| 1. Temporal and spatial distribution of fish communities (including spotted scat and tade mullet) in Pak Phanang mangrove forest | ● Fish communities collection<br>- Fish larvae and juveniles were collected by using push net, trawl net and plankton net. Adult fish were collected by using gill net.<br>- The samples of larval fish were identified based on the references by Okiyama (1988) and Leis and Carson-Ewart (2000) and counted to determine density. Juvenile and adult fish were identified based on the references by Carpenter and Niem (1999) and Carpenter and Niem (2001). Measurement of total length and weight in wet weight were also determined. All samples were preserved in the 10% neutralized formalin solution.<br>● Environmental parameters: Physical and chemical factors were conducted *in situ*. |
| 2. Food sources in mangrove forest<br>- Species and biomass of microphytoplankton<br>- Species and biomass of zooplankton<br>- Species and biomass of benthos<br>- Grain size and organic matter content | ● Food sources in mangrove forest<br>- Species and biomass of microphytoplankton: Microphytoplankton samples were collected by using plankton net with 20 micrometer mesh size. Microphytoplankton preserved in neutral formalin 2%, later identified and enumerated for density on Sedgwick-Rafter slide.<br>- Species and biomass of zooplankton: Zooplankton collected by using plankton net in 103 and 330 micrometer. Zooplankton samples were fixed and preserved in the dilute neutralized seawater formalin solution and enumerated for dominant taxa.<br>- Species and biomass of benthos: Macrobenthic fauna at each station were collected in three replicated 50x50 cm quadrat samples as well as three core samples of 15 cm inner diameter at the depth of 30 cm. Samples from quadrats were sieved through 0.5 mm mesh sieve. Soil samples from the core samples were also sieved through 0.5 mm mesh sieve. Pneumatophores and mangrove |

| Research Attributes | Methodology |
|---|---|
| 2. (Continued) | seedlings were removed prior to the quadrat and core collection. Modified Petersen Grab sampler was used to collect samples in Pak Phanang River and Estuary and sieved through 0.5 mm mesh sieve residues were then washed in sea water and fixed in 10 % neutralized formalin solution for further sorting and identification.<br>- Grain size and organic matter content: Sediment samples of approximately 50 g collected were for grain size analyzed by Hydrometer Method (Chinabut and Chirmsiri, 1993). Organic content analyses were carried out following the wet oxidation method (Chairoj, 1993). |
| 3. Spotted scat fishery in survey in Pak Phanang Estuary | ● Fishery survey based on questionnaires among the local fishermen in Pak Phanang Bay was conducted inorder to estimate the fishery status of spotted scat during May 2004-October 2005. |
| **Feeding Ecology in Spotted Scat,**<br>***Scatophagus argus*** | |
| 1. Feeding types in spotted scat | ● Feeding structure morphology and digestive system: Feeding structure morphology and digestive system namely mouth position, teeth, gill rakers, shape of stomach, number of pyloric caeca and intestinal length in fish of three size class were determined. |
| 2. Spotted scat stomach content analysis<br>- Points method<br>- Index of Relative Importance in food types<br>- Carbon/nitrogen analysis in food | ● Spotted scat stomach content analysis<br>- Food items in stomach of three sizes were identified to taxon with results presented as food items in diet composition. Enumeration of food items followed the method of Williams (1981).<br>- The main food items were identified using the index of relative importance (IRI) of Pinkas *et al*. (1971), as modified by Hyslop (1980).<br>- Carbon/nitrogen content in organic matter in food of different stages of spotted scat by CHN analyses. |

| Research Attributes | Methodology |
|---|---|
| 3. Spotted scat feeding preference in each stage<br><br><br><br><br><br>4. Ontogenetic niche shift in spotted scat | ● Spotted scat feeding preference in each stage: Feeding preference experiment concluded based on the feeding ecology results by selection of microphytoplankton (*Chaetoceros* sp., *Skeletonema* sp.) and zooplankton (rotifers) for fish in three size classes feeding. Data were analyzed by Manly's Alpha Preference Index.<br>● Conclusion of niche shift according to the result of feeding types, stomach content in each stage and carbon/nitrogen analysis in food. |
| **Histological Adaptations in Digestive System and Feeding Efficiency**<br>1. Histology adaptations in digestive system | ● Histology of feeding structure morphology: Digestive tract tissues in three size classes were embedded in paraffin and cut to 4 micrometer thickness, stained with Hematoxylin and eosin; alcian blue and Periodic Acid Schiff's (PAS). Tissue sections were observed under light microscope and the histological finding was recorded (Burkitt *et al*., 1993; Takashima and Hibiya, 1995). Histological details were linked to feeding structure morphology. |
| 2. Digestion and assimilation efficiency in each stage | ● Digestion efficiency in each stage: Digestion and assimilation efficiency were analyzed by Proximal analysis method. The results were calculated in equation to determine the gross energy (GE). |
| **Niche Partitioning in Spotted Scat and Adult Tade Mullet**<br>1. Feeding types in tade mullet<br>2. Tade mullet stomach content analysis<br>3. Niche overlap in spotted scat and tade mullet | ● Feeding structure morphology and digestive system namely mouth position, teeth, gill rakers, shape of stomach, numbers of pyloric caeca and intestinal length of tade mullet were measured and counted.<br>● Food items were examined and analyzed by Index of Relative Importance in food types.<br>● Food spectra in spotted scat and tade mullet were compared and analyzed for niche overlap in food items of both species. |

## G. Objectives

The scope of this research provide the assessment on the role of mangrove reforestation in Pak Phanang Estuary, Nakhon Si Thammarat Province on fish communities in particular spotted scat, *Scatophagus argus* through feeding strategies in different stages in relation to feeding structure morphology, development of digestive system and assimilation efficiency. Moreover, the trophic role of this fish in the mangrove food webs will be elucidated.

1. To assess the importance of mangrove forests as food sources for spotted scat, *Scatophagus argus* through feeding strategies in different stages in relation to feeding structure morphology, development of digestive system and assimilation efficiency.

2. To determine the trophic role of spotted scat, *Scatophagus argus* in mangrove food webs.

3. To study niche partitioning in spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* sharing the same food resources in the mangrove forests.

## H. Expected Results

1. The results provide in depth knowledge in mangrove ecology on niche partitioning and food webs in dominant fish in mangrove forests.

2. The results can be used as the baseline information in promoting *Scatophagus argus* as one of the important aquaculture species.

# CHAPTER II

# IMPORTANCE OF PAK PHANANG MANGROVE FOREST FOR FISH COMMUNITIES

## A. Introduction

Pak Phanang mangrove forests were once the pristine and productive riverine mangrove forests. Dominant pioneer species in the area were *Avicennia marina*, *A. officinalis*, *A. alba*, *Sonneratia caseolaris* and *S. alba*. Other dominant species replacing these pioneer species were *Rhizophora mucronata*, *R. apiculata*, *Xylocarpus granutum*, *Bruguiera gymnorrhiza*, *B. sexangula*, *B. parviflora*, *B. cylindrica*, *Ceriops decandra*, *C. tagal*, *X. moluccensis* and *Lumnitzera* spp. (Srisawasdi, 1991). Pak Phanang Estuary is one of the most productive in term of fishery production. During 1975-1996, the mangrove forest in Nakhon Si Thammarat had greatly decreased by 54.30% or approximately 44,274 rai (Charuppat and Charuppat, 1997). The rapid decline of mangrove forest was due to the expansion of shrimp farms at Pak Nakhon, Pak Poon, Tha Rai and Pak Phanang areas (Platong, 1998). Mangrove reforestation program in Nakhon Si Thammarat has begun since 1982 on the accreted mudflats in particular on the eastern coastline of the Pak Phanang Bay. Thus, the mangrove forests in Pak Phanang Estuary had gone through the phases of pristine and productive forest to deteriorated forests and mangrove plantations of different ages. At present, Pak Phanang mangrove forests stretched total 59,172.85 rai (Office of Natural Resources and Environmental Policy and Planning, 2004). Several studies of mangrove associated with fish communities in Pak Phanang Bay provided evidences that these mangrove forests were used by fish as nursery grounds, permanent habitats, breeding and feeding grounds (Sirimontarporn *et al*., 1997; Sirimontarporn, 1998; Somkleeb *et al*., 2001; Srithakon *et al*., 2003; Paphavasit *et al*., 2004). Tongnunui *et al*. (2007) has revised the data on the fish assemblage in Pak Phanang Bay, a total of 90 taxa in 39 families were reported. Comparison of number of species and species composition were made among the mangrove plantation, embayment and degraded forests.

The role of mangrove reforestation supported the availability of habitats and food sources for fish communities. The increase in organic detritus in term of forest biomass as the mangrove plantation aged. Benthos and zooplankton were also high in term of biomass and diversity. These zooplankton and benthos provided alternative food sources for fish. As the forest grew, they provided the complex root system as shelters and habitat for these fish. Therefore this study aimed to assess the importance of Pak Phanang mangrove forest for fish communities through changes in fish assemblage structure in mangrove plantations of different ages. Mangrove utilization by fish communities was determined. Special attention was focus on the abundance and distribution of spotted scat *Scatophagus argus* in the Pak Phanang Estuary. State of mangrove dependency in different stages of spotted scat was also carried out.

## B. Literature Review

### 1. Importance of Mangrove Forests for Fish Communities

Mangrove forests support fisheries production by providing nursery grounds for larval and juvenile marine fish (Nagelkerken *et al*., 2000) due to their high prey abundance and their role as a predation refuge (Acosta and Butler, 1999). Juvenile survival may be enhanced in shallow mangrove habitats where structural complexity, shading, and turbidity are relatively high (Laegdsgaard and Johnson, 2001; Ellis and Bell, 2004). Another hypothesis focuses on the refuge from predation provided by soft mud suitable for burrowing and the habitat complexity resulting from prop roots, pneumatophores and mangrove debris. Also, the long residence time of water in mangroves physically retains immigrating larvae and juveniles (Chong *et al*., 1996), thus supports fisheries production. Marine fish use mangrove habitats transiently as foraging grounds, reproductive grounds (Chaves and Bouchereau, 2000), or move in when environmental conditions in diel or seasonal cycles are favorable e.g. at high tide or with increased salinity or temperature (Barletta *et al*., 2005). Mangroves can provide a refuge from predation because of their high habitat complexity (Sheaves, 2001). Moreover the retention of litter falls within the mangrove forest creates a detrital based food web, often considered to explain why many fish and crustacean species utilize mangroves (Robertson and Blaber, 1992).

Fish in mangrove forests can be categorized into three groups according to life history strategies

1. True residents, which spend their complete life cycle by reproducing and feeding within mangrove habitats. Fish that can withstand a wide range of salinities are euryhaline. These fish often small and numerous, numerically dominating the mangrove fish fauna (Blaber, 1997), These true resident fish in different mangroves were *Zenarchopterus dunckeri* and *Periophthalmus vulgaris* in Okinawa mangrove (Shokita, 2000), *Tachysurus caelatus*, *Macrones guilo*, *Zenarchopterus dispar*, *Hemirhamphus marginatus*, *Pseudarius platystomus*, *Periophthalmus koelreuteri P. sobrinus* and *Liza macrolepis* in Negombo Estuary, Sri Lanka

(Pinto and Punchihewa, 1996) Other fish in the families namely Clupeidae, Mugilidae, Atherinidae, Ambassidae, Carangidae, Leiognathidae, Gerreidae and Teraponidae dominated East Africa, Australian, Madagascar and Taiwanese mangroves forests (Little *et al*., 1988; Halliday and Young, 1996; Laroche *et al*., 1997; Lin and Shao, 1999). True residents in Thai mangrove forests were namely fish in the families Engraulidae, Clupeidae, Leiognathidae, Gerreidae, Eleotridae and Gobiidae (Satapoomin and Poovachiranon, 1997; Tongnunui, 1997; Vitheesawat, 1999; Somkleeb *et al*., 2001).

2. Partial residents, ephemeral visitors or transients enter the mangrove system seeking for nursery ground, usually spawning and spending much of their adult life at sea, but often returning seasonally to estuaries. Small larvae or early juveniles often grow rapidly and leave the system before maturing in the adjacent estuary. The most common Indo-Pacific species are *Terapon jarbua*, *Gerres oyena*, *G. filamentosus*, *Saurida gracilis*, *Siganus guttatus*, *Lutjanus argentimaculatus* and *Carcharinus leucus* found dominant in mangrove creeks. *T. jarbua* and *G. oyena* are being associated particularly with shallow waters as juveniles (Shokita, 2000); *Lutjanus fulviflammus* is linked clearly with mangroves as juveniles (Thollot, 1992); *Mugil cephalus* and *Sphyraena barracuda* are ubiquitous species, the first being common in shallow waters both as juveniles and adults usually characterized as marine spawners (Fischer and Bianchi, 1984).

Another group of partial residents are those fish utilize mangrove systems to forage, or to seek refuge from predation in juvenile and adult stages. The size frequency distribution of *H. sciurus* suggested an ontogenetic shift in habitat use from seagrass, to mangroves, to patch reefs, and finally to fore reefs, in their adult phase. Juvenile *H. sciurus* migrate from seagrass beds when they reach a length of 4–6 cm. Migration occurs from seagrass to mangroves, but if mangroves are absent *H. sciurus* move to reefs. Because mangroves offer refuge and the number of *H. sciurus* predators is greater on reefs than in mangroves, the chances of grunt survival may be lower if grunts migrate directly to reefs (Mumby *et al*., 2004). The forest habitat was not only used by small fish, but was also a regular feeding site for sub adult in size less than 50 cm such as *Lates calcarifer*, *Acanthopagrus berda* and to a less extent mangrove jack, *Lutjanus argentimaculatus*. Among partial residents, the long-term residents inhabit mangroves for several consecutive months, notably *Gerres acinaces* and *Caranx papuensis*. The short term residents occupy the mangroves irregularly, for example *Valamugil seheli*, *Liza melinoptera* and *Scomberoides commersonianus* (Laroche *et al*., 1997). Partial residents which utilized Thai mangrove area as spawning and nursery grounds were fish in the families Mugilidae and Atherinidae. Juvenile and adult stages of Synodontidae, Exocoetidae, Ambassidae, Mullidae, Teraponidae, Blenniidae, Soleidae, Cynoglossidae, Scatophagidae and Monacanthidae visit mangroves as feeding sites (Vatanachai, 1979a; Chamchang, 1991; Monkolprasit, 1983; UNDP/UNESCO, 1991; Janekarn, 1993; Chayakul, 1996; Aiemsomboon *et al*., 1997; Tongnunui, 1997; Vitheesawat, 1999; Somkleeb, *et al*., 2001; Paphavasit *et al*., 2002;Tongnunui *et al*., 2002).

3. Marine migrants use mangrove forests as feeding in short time period following the tidal cycles and also some marine species that pay regular seasonal visits to estuaries, usually as adults searching for food such as *Dasyatis sephen* (Shokita, 2000). Post larvae and juveniles of several species of Engraulidae and Clupeidae moved into the forests in vast numbers on flood tides and feed on zooplankton (Satapoomin and Poovachiranon, 1997; Robertson *et al*., 1988; Chaves and Bouchereau, 2000). Robertson and Duke (1990) found many fish in mangroves which used the forest at high tide moved into shallow creeks on the ebb tide and creeks supported very high standing stocks of fish at low tide. However several pelagic, schooling species, which were not captured in small creeks or were presented by very small numbers such as *Stolephorus* spp., *Encrasicholina devisi*, *Escualosa thoracata*, *Sardinella albella* and *Herklotsiehthys castelnaui*, may move into the mainstream of the estuary at low tide.

Tidal range and the time of day or night also influence the composition and abundance in the fish assemblage based on marine migrants. Some piscivore (*Scomberoides commersonianus*, *S. tol*, *Tylosurus acus melantous*) are associated with spring tides and therefore require a minimum water height to enter the mangrove. The large tidal range leads to relatively deep waters at high tide which may increase piscivorous predation on small sized fish, while the time of day or night had also an influence on the fish assemblage (Laroche *et al*., 1997). The day association was very marked for some species such as *Bothus pantherinus*, a benthic invertebrate feeder which fed essentially during the day. The fish of the family Gerreidae probably leave the mangrove before dusk (Rooker and Dennis, 1991). The nocturnal species included one piscivore, *Chirocentrus dorab*, which was particularly active at night (Blaber *et al*., 1995). The nocturnal feeding trend of some Mugilidae was observed also for *Mugil cephalus* in South Africa (Day *et al*., 1981) and for *Liza grandisquamis* in Nigeria (King, 1984).

**2. Mangrove Forests as Food Sources**

The mangrove forests provide a greater abundance of food, due to the claimed high productivity of the mangroves and the associated epi- and benthic fauna and, hence, greater abundances and diversity of fish (Laegdsgaard and Johnson, 2001). Food sources are the major factors to induce fish into mangrove forest. Plankton, mainly microphytoplankton and dominant zooplankton such as copepod, crustacean larvae and bivalve larvae are important food sources.

Mangrove benthos namely nematodes, gastropods, polychaetes, crustaceans and crabs are also major food sources for fish. Stomach content analysis in mangrove fish revealed benthos as major food items. Thong and Sasekumar (1984) found the stomach content comprised of 64 % as benthos. Boonruang *et al*. (1994) also found benthos of 38 % in stomach contents comprised of Penaeidae, Caridae nematodes, amphipods, molluscs, ostracods and mysids. Boonruang and Satapoomin (1997) found 53.5% benthos and 31-34% zooplankton in the stomach content of mangrove fish. Moreover, copepod and detritus are found as major food items ranging from 9.1-17 % in fish stomach contents (Thong and Sasekumar, 1984; Boonruang *et al*., 1994; Boonruang and Satapoomin, 1997). For *Ambassis kopsii*, calanoid copepods alone contributed more than 50% in the diets of all samples and cypris, the second important item, made up more than 10%. Cypris was the most dominant food item for *Atherinomorus duodecimalis* and *Stolephorus indicus* (Hajisamae *et al*., 2003). However, other major food components such as insects, crabs and crab megalopa, also contributed greatly to the diets of fish from Malaysian mangrove (Leh and Sasekumar, 1991).

Feeding types of dominant fish in Gulf of Thailand and Andaman Sea in estuarine and mangrove forests are shown in Table 2.1 and Table 2.2. According to the feeding types in mangrove fish as reported by Monkolprasit (1983), UNDP/UNESCO (1991), Monkolprasit (1994), Boonruang *et al*. (1994), Laroche *et al.* (1997), Lukoschek and McCormick (2001), Paphavasit *et al*. (2002), Schafer *et al*. (2002) and Almeida (2003), fish in mangrove forest can be divided into four groups namely:

1. Herbivore: Many species incorporate plants, either algae such as cyanobacteria, green algae, diatoms and dinoflagellates or macrophytes, as part of their diet. Fish in this group are Cyprinidae, Mugilidae, Hemiramphidae, Syngnathidae, Ambassidae, Leiognathidae, Gerreidae, Ephippidae, Gobiidae, Periophthalmidae, Scatophagidae, Chaetodontidae, Stromateidae, Cynoglossidae, Triacanthidae and Tetraodontidae. Many of the species consume unicellular algae and diatoms, such as the iliophagous species may be regarded as partially herbivorous.

2. Carnivore: The major food items were *Acetes* spp., copepods, penaeid shrimps and crabs. Fish families in this group are Engraulidae, Bagridae, Ariidae, Plotosidae, Ambassidae, Lutjanidae, Mullidae, Teraponidae, Sciaenidae, Trichiuridae, Scombridae, Eleotridae and Gobiidae. In addition, fish were divided in 3 sub groups namely:

- Principally zooplankton feeder: food items consist mainly of copepods and crustacean larvae. Furthermore, the proportions of zooplankton in diet of small sized fish species are dependent upon their habitat use as food availability. Typical fish families in this group are

Engraulidae, Clupeidae, Atherinidae, Hemiramphidae, Ambassidae, Leiognathidae, Polynemidae and Chaetodontidae.

Table 2.1 Feeding types of dominant fish in estuarine and mangrove areas in the Gulf of Thailand

| Study areas | Dominant Families | Feeding types |
|---|---|---|
| Bang Prakong River mangrove forest,<br>Chachoengsao Province (Yimchang, 2001) | Cyprinidae<br>Engraulidae Clupeidae<br>Ambassidae Eleotridae Gobiidae<br>Ariidae Sciaenidae | Herbivore<br>Zooplankton feeder<br>Carnivore/Omnivore<br>Carnivore |
| Tha Chin Estuary, Samut Sakhon Province<br>(Vatanachai, 1979b; Vitheesawat, 1999;<br>Aiemsomboon, 2000) | Engraulidae Clupeidae<br>Polynemidae Sciaenidae<br>Mugilidae Ambassidae Gobiidae | Zooplankton feeder<br>Carnivore<br>Carnivore/Omnivore |
| Klong Kone mangrove forests,<br>Samut Songkhram Province<br>(Aiemsomboon *et al*.,1997) | Clupeidae<br>Leiognathidae<br>Polynemidae<br>Mugilidae Gobiidae Ambassidae | Zooplankton feeder<br>Carnivore/Detritivore<br>Carnivore<br>Carnivore/Omnivore |
| Laem pak-bia mangrove forest,<br>Phetchaburi Province (Vatanachai, 1979a) | Syngnathidae<br>Mugilidae Ambassidae Gobiidae | Herbivore<br>Carnivore/Omnivore |
| Klongwan mangrove forest, Prachuap Khiri<br>Khan Province (Sontirat, 1982) | Megalopidae Elopidae<br>Scatophagidae | Carnivore<br>Carnivore/Detritivore |
| Ban Don Bay mangrove forest,<br>Surat Thani Province (Monkolprasit, 1994) | Mugilidae Leiognathidae Scatophagidae | Omnivore |
| Mangrove plantations on new mudflat areas<br>and abandon shrimp farms, Nakhon Si<br>Thammarat Province (Paphavasit *et al*., 2004) | Engraulidae Clupeidae Hemiramphidae<br>Megalopidae Bagridae Ariidae<br>Platycephalidae Gerreidae Teraponidae<br>Mugilidae Ambassidae Leiognathidae<br>Eleotridae Gobiidae Scatophagidae<br>Adrianichthyidae Phallostethidae<br>Cichidae | Zooplankton feeder<br>Carnivore<br><br>Carnivore/Detritivore<br><br>Carnivore/Omnivore<br>Omnivore |

Table 2.2 Feeding types of dominant fish in estuarine and mangrove areas on Andaman coastline

| **Study areas** | **Dominant Families** | **Feeding types** |
|---|---|---|
| Mangrove forests and coastal area, Ranong Province (UNDP/UNESCO, 1991; Boonruang and Satapoomin, 1997; Duangdee *et al*., 1998) | Engraulidae Clupeidae Atherinidae | Zooplankton feeder |
| | Centropomidae Leiognathidae Carangidae Polynemidae | Carnivore |
| | Mugilidae Ambassidae Blenniidae Gobiidae | Carnivore / Omnivore |
| Phangnga Bay mangrove forest, Phangnga Province (Janekarn, 1993; Monkolprasit ,1994; Sutthakorn, 1994; Boonruang *et al*., 1994; Satapoomin and Poovachiranon, 1997) | Engraulidae | Zooplankton feeder |
| | Ariidae Platycephalidae Leiognathidae Gerreidae Carangidae Sciaenidae Nemipteridae Callionymidae Teraponidae Monacanthidae | Carnivore |
| | Mugilidae Ambassidae Gobiidae | Carnivore / Omnivore |
| East coast mangrove forest, Phuket Province (Satapoomin and Poovachiranon, 1997) | Engraulidae Clupeidae | Zooplankton feeder |
| | Carangidae | Carnivore |
| | Leiognathidae | Carnivore / Detritivore |
| | Mugilidae Gobiidae | Carnivore / Omnivore |
| Sikoa mangrove forest, Trang Province (Tongnunui, 1997; Tongnunui *et al*., 2002) | Clupeidae | Zooplankton feeder |
| | Leiognathidae Blenniidae Gobiidae | Carnivore / Omnivore |
| Satun mangrove forest, Satun Province (Angsupanich *et al*., 2001) | Ambassidae Leiognathidae Gobiidae | Carnivore / Omnivore |

- Principally benthic invertebrate feeders: food items are meiofauna and macrobenthic invertebrate. Coull *et al.* (1995) stated that many bottom feeding juvenile fish pass through on obligatory meiobenthos feeding stage. Families in mangrove recorded are Ophichtyidae, Ariidae, Plotosidae, Mugilidae, Belonidae, Platycephalidae, Ambassidae, Lutjanidae, Leiognathidae, Sillaginidae, Polynemidae, Apogonidae, Carangidae, Mullidae, Pomadysidae, Callionymidae, Eleotridae, Periopthalmidae, Bothidae, Cynoglossidae and Balistidae.

- Piscivore: These fish are the top predators apart from other vertebrate. Although larger fish are piscivore, many smaller species also incorporate fish in their diets. The main piscivorous families are Muraenesocidae, Congridae, Chirocentridae, Synodontidae, Ariidae, Plotosidae, Scorpaenidae, Belonidae, Centropomidae, Carangidae, Serranidae, Sciaenidae, Pomadayidae, Sphyraenidae, Trichiuridae, Scomberoides and Psettodidae.

3. Detritivore: Some fish can feed on decaying matter and organic detritus. Most fish tend to feed either directly or indirectly on detritivorous invertebrates (Wootton, 1992). Other included in this category are plant tissue, diatom, algae and foraminifera. Mugilidae, Leiognathidae, Gerreidae, Periopthalmidae, Eleotridae, Gobiidae, Cynoglossidae, Batracoididae, Scatophagidae and Siganidae were classified into this group.

4. Omnivore: This group feeds on benthic algae such as diatoms, microfauna including Foraminifera and Flagellata and to a lesser extent small meiofauna, as well as indeterminate particulate organic matter usually of plant origin, sometime referred to as detritus, all the small organisms in or on the surface layer of the substratum and associated organic matter. To feed they ingest relatively large volumes of sand or mud, digest the food material and pass out the inorganic particles. The dominant groups are Mugilidae, Hemiramphidae, Leiognathidae, Teraponidae, Drepanidae, Eleotridae, Gobiidae, Ostraciidae, Scatophagidae and Tetraodontidae.

## C. Materials and Methods

### 1. Quantitative Study of Fish Communities

Fish larvae were collected by using the plankton net of 103 and 330 μm mesh conical net equipped with a flowmeter. The plankton net was towed with low-speed boat at each station. Two replicates were collected for each station. Samples were then preserved in 4% neutralized formalin solution and enumerated for dominant taxa following Okiyama (1988) and Leis and Carson-Ewart (2000). Juvenile fish were collected by using the fry sweeper the modified push net of 2 mm mesh size and 3 mm mesh size of trawl net. Towing were conducted at daytime low tides. Adult fish from study sites were collected by using the 1 cm mesh size local gill net for half hour in two replicate samples during low tide at day time at each station by moving back and forth along the shoreline in waist-to-chest deep water. Juvenile and adult fish were sorted, identified and recorded the number of individuals based on the references by Carpenter and Niem (1999) and Carpenter and Niem (2001). Fish measurement namely total length (TL) and weight in wet weight was carried out. Fish further preserved in the 10% neutralized formalin solution for detailed identification.

### 2. Food Sources in Mangrove Forest

#### 2.1 Species composition and abundance of microphytoplankton

At each station, a depth integrated 20 litre of water samples were collected by the Van Dorn water sampler. Water sample then filtered through 20 μm mesh size plankton net. Microphytoplankton was preserved in 2% neutralized formalin. Identification and density of microphytoplankton were later determined. Microphytoplankton density was enumerated and counted on the Sedgwick-Rafter slide.

#### 2.2 Species composition and abundance of zooplankton

Zooplankton samples were collected by using the plankton net of 103 and 330 μm mesh conical net equipped with a flowmeter. Duplicate horizontal tows were conducted with low-speed boat at each station. Towing was conducted at the time periods of high tide-slack water-low tide. Samples were fixed and preserved in the neutralized formalin solution at the final concentration of 4%. Samples and were further enumerated for dominant taxa.

**2.3 Species composition and abundance of benthos**

Macrobenthic fauna at each station were collected in three replicated 50x50 cm quadrat samples as well as three core samples of 15 cm inner diameter at the depth of 30 cm. Samples from quadrats were sieved through 0.5 mm mesh sieve. Soil samples from the core samples were also sieved through 0.5 mm mesh sieve. Pneumatophores and mangrove seedlings were removed prior to the quadrat and core collection. Modified Petersen Grab sampler was used to collect samples in Pak Phanang River and Estuary and sieved through 0.5 mm mesh sieve. The sieving residues were then washed in sea water and fixed in 10 % neutralized formalin solution for further sorting and identification. Benthos were identified to the lowest taxonomic category possible. Density of the benthos was also determined.

**2.4 Total forest biomass**

Total forest biomass is determined as the representative of detrital food source availabled. After collection of animals for the benthic community study, above ground parts of pneumatophores and seedlings as well as underground parts were washed carefully to remove soil, and then separated into components: live cable roots, dead cable roots, nutritive roots, and debris (dead branches, dead leaves and dead fruits) in order to determine underground, penumatophore and seedling biomass. The collected tissues were dried to a constant mass at $70^{o}c$ and weighed.

**2.5 Grain size and organic content**

Sediment samples of approximately 50 g were collected for grain size analyzed by Hydrometer Method (Chinabut and Chirmsiri, 1993). Organic content analyses were carried out following the wet oxidation Walkey-Black method (1947) (Chairoj, 1993).

**3. Environmental Factors**

Measurements of physical and chemical factors namely salinity, temperature and dissolved oxygen, water depth and transparency were conducted *in situ* at surface and bottom water with S-C-T meter, portable oxygen meter and secchi disc respectively.

**4. Data Analyses**

Effects of low and high salinity (year and month) and station on fish assemblage such as fish abundance with food source namely density of microphytoplankton, density of zooplankton and mangrove forest biomass were tested using a one-way analysis of variance (ANOVA). A posteriori Tukey's HSD test at significance level of $p < 0.05$ was used in all tests. ANOVA revealed a significant interaction between stations, independent simple *t*-test was used to compare the mean numbers between low and high salinity period. Prior to the analyses, data were transformed to [$\log_{10}(x+1)$] the normality of distribution. The Pearson Correlation between the environmental parameters and food sources with abundance of fish during high and low salinity period were also analysed. The correlation coefficients were compared at significant level of $p < 0.05$.

**5. Spotted Scat Fishery Survey in Pak Phanang Estuary**

Fishery survey based on questionnaires among the local fishermen in Pak Phanang Bay was conducted inorder to estimate the fishery status of spotted scat during May 2004-October 2005. Data on questionnaires consisted namely of fishing efforts in the bay, fishing gear, total catch, dominant species and status of fishery and fishery biology related data. Data on spotted scat fishery concentrated on the fishing ground, abundance and distribution, spawning season and spawning areas and status of spotted scat fishery. The questionnaire used in this fishery survey as in the Appendix 1.1.

## D. Results and Discussions

### 1. Assessment on the Role of Mangrove Plantations on Fish Communities in Pak Phanang Estuary

#### 1.1 Species composition and abundance

The role of mangrove plantations in Pak Phanang Estuary supported the availability of habitat and food sources. Of the total 50 species of fish recorded in 27 families in different stages found in the mangroves as in Table 2.3. The species composition and abundance in fish communities in mangrove plantations of different age showed that PP1 (Klong Bang Hua Koo) supported the highest density of fish larvae and juveniles. This station provided habitat complexity in term of resulting microhabitat diversed mangrove plant species. This mangrove plantation were 37 years old similar to the natural mangrove forest. *Rhizophora mucronata* and *R. apiculata* were dominant species. The mangrove floor was flooded only during spring tide. *Nypa fruticans* communities were found scattered in the area as well as *Acrostichum aureum*, *Derris trifoliate* and *Acanthus* spp. Seedlings *Bruguiera sexangula* and *Xylocarpus moluccensis* were found in the area. There is evidence that the structure provided by the prop roots, pneumatophores and tree debris, as well as invertebrate burrows, in the mangrove forests, provide larvae and juveniles protection from predation by larger fish (Ley and McIvor, 2001). In addition, marine fish families Clupeidae, Atherinidae, Syngnathidae and Sphyraenidae were found in low salinity period. They enabled drift from the adjacent marine environment to mangrove forests. These forests were under the influence of tides, large volume of water exchanged during the ebbs and flows. The salinity regime makes the water body more heterogenous during wet season, there by supporting a diverse fish fauna with different osmoregulatory capacity. Typical brackishwater condition prevails in the mangroves during wet season. Such conditions are conductive for breeding of these brackishwater fish fauna such as family Gobiidae was mostly typical brackishwater fish and their intensive breeding in the wet season results in relatively more larval abundance. Thus high abundance of planktonic larvae in wet season released by the mangrove intertidal fauna was the important food sources for these young fish stages (Termvidchakorn and Paphavasit, 1999).

Of the total 14 families recorded, only 8 species in 6 families were found in adult phase. This was in contrast to the mangrove plantation at PP3 (Klong Gong Kong) that of the total 24 families recorded, 31 species in 19 families were found in adult phase. Mangrove plantation at

PP2 (Klong Bang Luk) supported fish in 20 families with adult phase recorded 18 species in 12 families. Fish in the families Ambassidae, Gobiidae, Scatophagidae and Cynoglossidae, as larvae, juveniles and adults, were recorded from all stations. Adult phase in the families Megalopidae, Bragidae, Mugilidae, Ambassidae, Eleotridae, Gobiidae and Scatophagidae were common throughout the year. When compared between stations and period of high and low salinity, the total number of fish captured were not significantly different ($p$>0.05). However during the period of high salinity, fish densities in all three stages were higher as compared to low salinity period.

Fish in 5 families seek mangrove forest as nursery area found only in larval and juvenile stages namely Clupeidae, Atherinidae, Syngnathidae, Blenniidae and Sphyraenidae. The true resident species were found in 9 families of Engraulidae, Ambassidae, Leiognathidae, Gerreidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae and Cynoglossidae. All three stages were found indicating that they spent their complete life cycle in mangrove forest. They can withstand a wide range of salinities. While partial residents entering into the forest as feeding ground were those fish in the families Megalopidae, Bragidae, Arridae, Plotosidae, Mugilidae, Phallostethidae, Hemiramphidae, Aplocheilidae, Scorepaenidae, Sillaginidae, Sciaenidae, Callionymidae and Tetraodontidae. Juveniles and adults in these latter groups were found distributed in mangrove forest.

Table 2.3 Species lists of fish in various stages in Pak Phanang mangrove forests, Nakhon Si Thammarat Province during May 2004-October 2005

| Family | Species | Common name | Larvae | Juveniles | Adults |
|---|---|---|---|---|---|
| Megalopidae | *Megalops cyprinoides* | Indo-Pacific tarpon | - | - | + |
| Engraulidae | *Thryssa hamiltonii* | Hamilton's thryssa | - | - | + |
| | *Stolephorus insularis* | Hardenberg's anchovy | - | + | - |
| Clupeidae | | Herrings | + | - | - |
| | *Escualosa thoracata* | White sardine | - | - | + |
| | *Sardinella albella* | White sardinella | - | - | + |
| Bragidae | *Mystus gulio* | Long whiskers catfish | - | - | + |
| Ariidae | *Arius acutirostris* | - | - | - | + |
| Plotosidae | *Plotosus canius* | Gray eel-catfish | - | - | + |
| Mugilidae | *Liza planiceps* | Tade mullet | - | - | + |
| | *Chelon permata* | Broad-mouth mullet | - | - | + |
| Atherinidae | | Silversides | + | - | - |
| Phallostethidae | *Neostethus lankesteri* | - | - | + | - |
| Hemiramphidae | *Dermogynys pusilus* | Wrestling halfbeak | - | + | - |
| Aplocheilidae | *Aplocheilus panchax* | Blue panchax | - | + | - |
| Syngnathidae | | Pipefish | + | - | - |
| Scorpaenidae | *Vespicula trachinoides* | Goblinfish | - | + | - |
| Ambassidae | | Asiatic glassfish | + | - | - |
| | *Ambassis nalua* | Scalloped perchlet | - | + | + |
| | *Ambassis vachellii* | Vachelli's glass perchlet | + | + | + |
| | *Ambassis* sp. | - | + | + | - |
| Sillaginidae | *Silago sihama* | Silver sillago | - | - | + |
| Leiognathidae | *Leiognathus decorus* | Decorated ponyfish | - | + | + |
| | *Leiognathus* sp. | - | - | + | + |
| Gerreidae | *Gerres oyena* | Common silver-biddy | - | - | + |
| | *Gerres* sp. | - | - | + | - |
| Sciaenidae | *Dendrophysa russelli* | Goatee croaker | - | - | + |
| Callionemidae | *Callionymus sp.* | - | - | - | + |
| Blenniidae | *Omobranchus sp.* | - | + | - | - |
| Eleotridae | *Butis butis* | Duckbill sleeper | - | + | + |
| | *Butis humeralis* | Black spot sleeper | - | - | + |
| | *Butis koliometapon* | Mud sleeper | - | + | + |
| | *Odonteleotris macrodon* | Gangetic sleeper | - | + | + |

Table2.3 (Continued)

| **Family** | **Species** | **Common name** | **Larvae** | **Juveniles** | **Adults** |
|---|---|---|---|---|---|
| Gobiidae | | Gobies | + | - | - |
| | *Acentrogobius canius* | Tropical sand goby | - | + | - |
| | *Acentrogobius kranjiensis* | - | - | + | - |
| | *Acentrogobius viridipunctatus* | Spotted green goby | - | + | + |
| | *Acentrogobius* sp. | - | - | + | + |
| | *Aulopareia cyanomos* | - | - | - | + |
| | *Brachygobius* sp. | - | - | + | - |
| | *Glossogobius guiris* | Tank goby | - | + | + |
| | *Glossogobius kokius* | Gobie kokou | - | + | - |
| | *Parapocryptes serperaster* | Large-scaled goby | - | - | + |
| | *Pseudogobius borneensis* | - | - | + | + |
| | *Pseudogobius javanicus* | - | - | + | - |
| | *Pseudapocryptes lanceolatus* | Point-tailed goby | - | - | + |
| | *Stignatogobius sadanundio* | - | - | + | + |
| | *Taeniodes cirratus* | Bearded worm goby | - | - | + |
| Scatophagidae | *Scatophagus argus* | Spotted scat | + | + | + |
| Siganidae | *Siganus canaliculata* | White-spotted spinefoot | - | + | - |
| | *Siganus javus* | Streaked spinefoot | - | - | + |
| Sphyraenidae | | Hammerhead | + | - | - |
| Cynoglossidae | *Cynoglossus bilineatus* | Fourlined tonguesole | - | - | + |
| | *Cynoglossus* sp. | - | + | + | - |
| Tetraodontidae | *Tetraodon nigroviridis* | Spotted green pufferfish | - | - | + |

Fish larvae in 9 families namely Clupeidae, Atherinidae, Synganthidae, Ambassidae, Blenniidae, Gobiidae, Scatophagidae, Sphyraenidae and Cynoglossidae were recorded with the total number of fish larvae 17,204 individuals/100 $m^3$ as in Table 2.3 and Figure 2.1. Family Gobiidae was the dominant group. Families Scatophagidae, Clupeidae and Ambassidae were ranked respectively in term of abundant. Fish larvae of economically importance in the area were in the families Clupeidae, Scatophagidae and Sphyraenidae. The abundance of this group was 2.52% of the total fish larvae. During the high salinity period, the average density of fish larvae was 3,361 individuals/100 $m^3$ as compared to the density of 6,940 individuals/100 $m^3$ in the low salinity period.

Families Ambassidae, Blenniidae and Gobiidae were abundance during low salinity corresponding to Ranong mangrove forest (UNDP/UNESCO, 1991). In addition, marine fish families Clupeidae, Atherinidae, Syngnathidae and Sphyraenidae were found in low salinity period. They enabled drift from the adjacent marine environment to mangrove forests. Because of relatively higher to tidal amplitude, the ebb and flow exchange more quantity of water with strong currents. The salinity regime makes the water body more heterogenous during wet season there by supporting a diverse fish fauna with different osmoregulatory capacity. Typical brackishwater condition prevails in the mangroves during wet season. Such conditions are conductive for breeding of these brackishwater fish fauna such as family Gobiidae was mostly typical brackishwater fish and their intensive breeding in the wet season results in relatively more larval abundance. In wet season, high abundance of planktonic larvae released by the mangrove intertidal fauna was the important food sources for these young fish stages (Termvidchakorn and Paphavasit, 1999).

Twenty seven species in 13 families of juvenile fish with the total number of 4,853 individuals were recorded. Family Gobiidae was the dominant group. Families Phallostethidae, Scatophagidae and Ambassidae were next in term of abundance. Other families recorded in the area were Engraulidae, Hemiramphidae, Aplocheilidae, Scorpaenidae, Leiognathidae, Gerreidae, Eleotridae, Siganidae and Cynoglossidae (Table 2.3, Figure 2.2). Juvenile fish of economically importance in the area were in the families Engraulidae, Scatophagidae and Siganidae. The abundance of this group was 10.20 % of the total juvenile fish. The average density in the low and high salinity period was 1,246 and 1,202 individuals respectively.

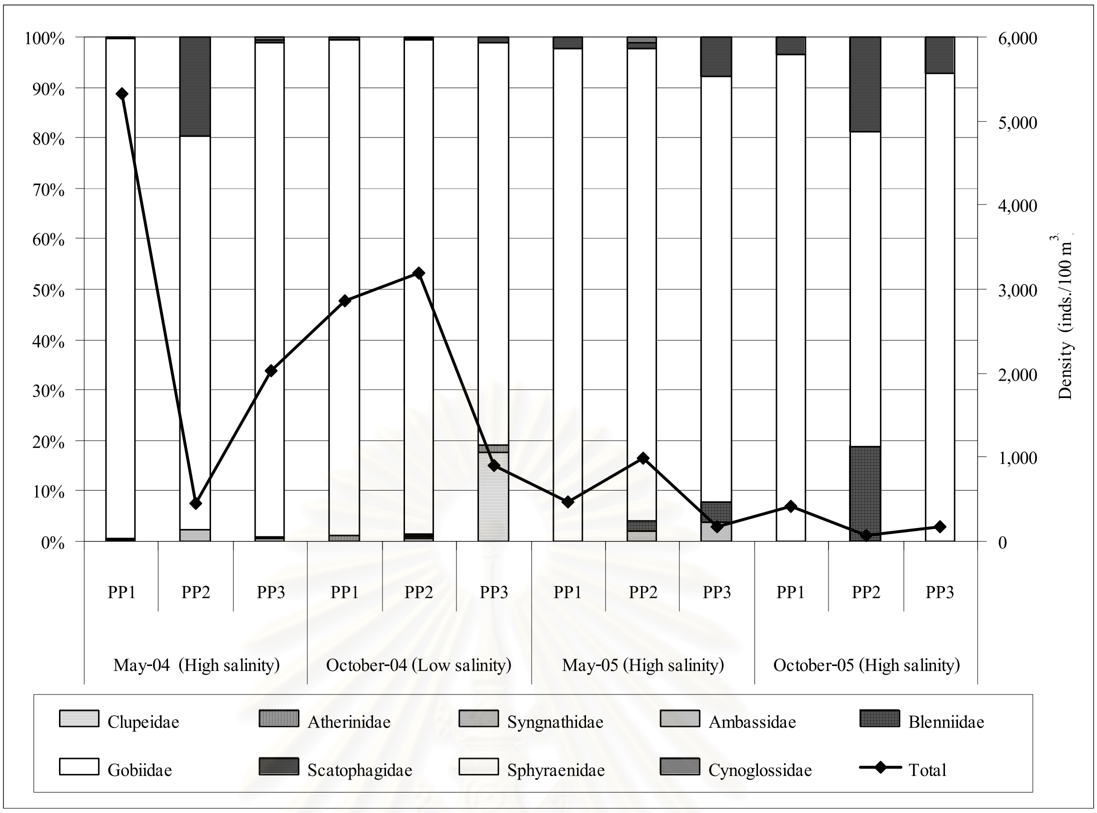



Figure 2.1 Fish larval abundance and distribution in each sampling areas in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

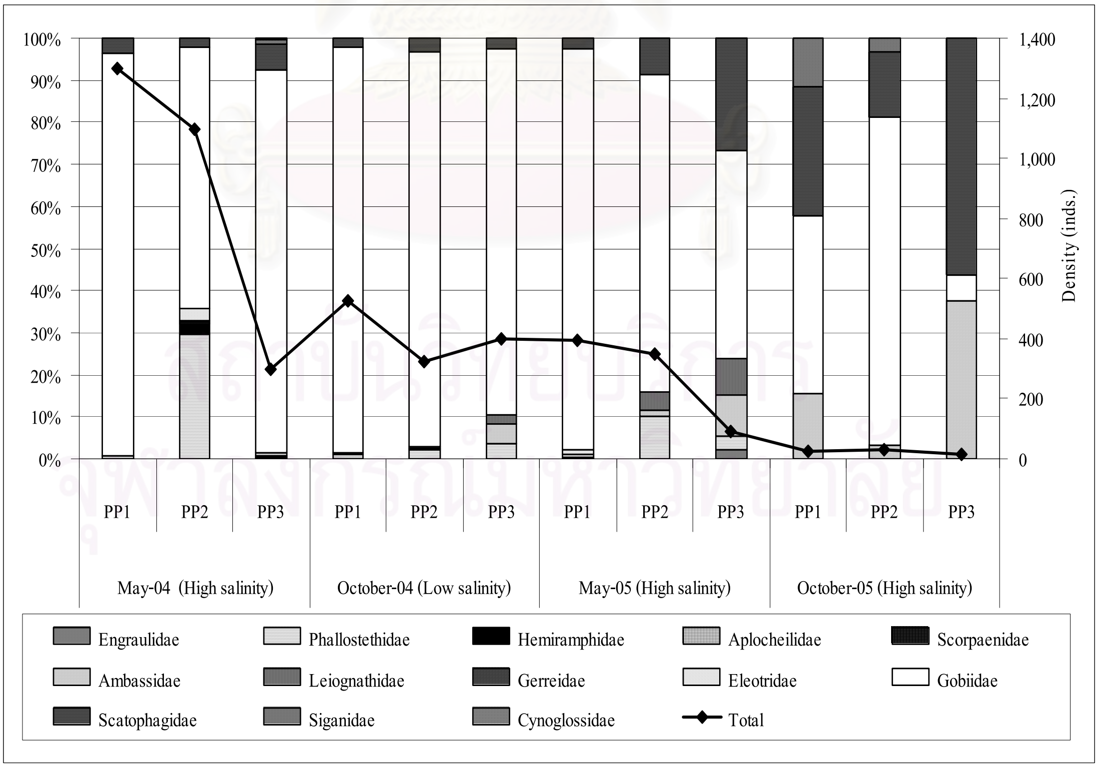



Figure 2.2 Juvenile fish abundance and distribution in each sampling areas in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

Total adult fish of 34 species in 19 families in the Pak Phanang mangrove forests were recorded namely Megalopidae, Engraulidae, Bagridae, Ariidae, Plotosidae, Mugilidae, Ambassidae, Sillaginidae, Leiognathidae, Gerreidae, Sciaenidae, Callionymidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae, Cynoglossidae and Tetraodontidae. Family Ambassidae was the dominant group. Fish in families Eleotridae, Scatophagidae and Gobiidae were next in term of abundance as shown in Table 2.3 and Figure 2.3. Fish of economically importance comprised of 22.03% of the total fish recorded. These were fish in the families Megalopidae, Engraulidae, Clupeidae, Bragidae, Ariidae, Plotosidae, Mugilidae, Sillaginidae, Sciaenidae, Scatophagidae and Siganidae.

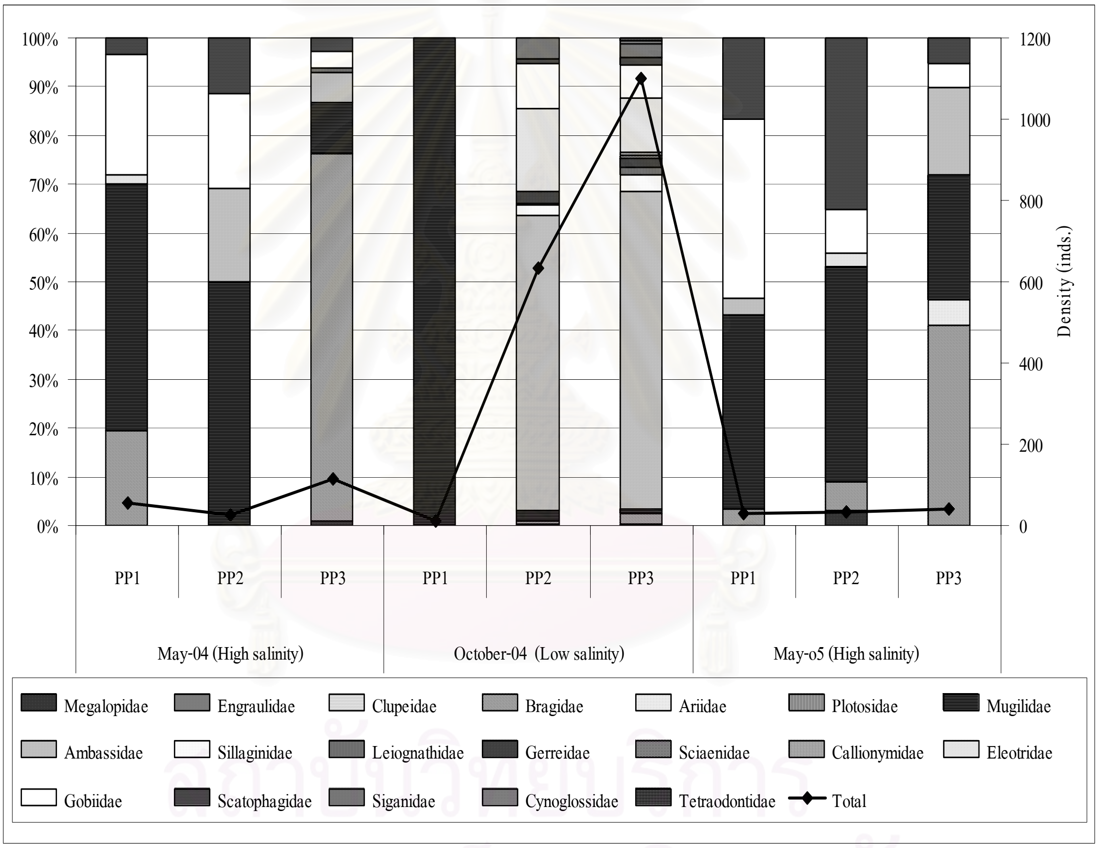



Figure 2.3 Adult fish abundance and distribution in each sampling areas in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

The common families (Gobiidae, Ambassidae, Scatophagidae, Phallostethidae and Eleotridae) in the Pak Phanang mangrove forests have often been recorded as abundant in mangroves and estuaries in other geographical regions (Blaber, 1997; Robertson and Blaber, 1992). The diversity of fish in this area was comparable to the previous reports in Pak Phanang Estuary from Sirimontaporn *et al.* (1997) and Sritakon *et al*. (2003) and other mangrove areas in the vicinity such as Pak Poon mangrove forest from Somkleeb *et al*. (2001) and Pak Nakhon mangrove forests by Sirimontaporn (1998). The latter two mangrove forests Pak Poon and Pak Nakhon, were degraded forests. The Pak Poon area was mainly abandoned shrimp ponds with mangrove reforestation efforts in certain area while the Pak Nakhon mangrove forests was degraded due to shrimp farms and urbanization. Low fish diversity were recorded (Somkleeb *et al*., 2001; Sirimontaporn, 1998). Leh and Sasekumar (1991) indicated that deforestation in mangrove creeks in Selangor, Malaysia led to a reduction in species richness of fish. In addition, mangrove deforestation in Singapore caused a decrease in species diversity of mangrove fish communities (Low and Chou, 1994). This would greatly affect the availability of habitat and food sources for fish. Higher diversity of fish recorded from this study was due to the study area extended into various mangrove plantations of different ages. Of the data on the fish assemblage in Pak Phanang Estuary reported only 21 species belonging to 13 families were consistent with this study. These fish were mainly tolerant to environmental changes and widely distributed in Pak Phanang Estuary namely *Stolephorus insularis*, *Thryssa hamiltonii*, *Escualosa thoracata*, *Sardinella albella*, *Mystus gulio*, *Plotosus canius*, *Chelon permata*, *Neostethus lankesteri*, *Vespicula trachinoides*, *Sillago sihama*, *Dendrophysa russelli*, *Butis butis*, *Acentrogobius canius*, *Acentrogobius viridipunctatus*, *Parapocryptes serperaster*, *Pseudapocryptes lanceolatus*, *Stigmatogobius sadanundio*, *Taenioides cirratus*, *Scatophagus argus*, *Siganus canaliculatus* and *Siganus javus* (Sirimontaporn *et al*., 1997; Sirimontaporn, 1998; Somkleeb *et al*., 2001; Sritakon *et al*., 2003; http://www.fishbase.org/search.php). As the result, *Scatophagus argus* is one of the dominant fish in Pak Phanang Estuary.

The dominant species in different aged mangrove plantation were *Acentrogobius viridipunctatus*, *Scatophagus argus*, *Ambassis nalua*, *Butis butis* and *Leiognathus decorus* corresponded with Sirimontaporn *et al.* (1997); Somkleeb *et al*. (2001); Assava-aree and Sriaroon (2005); Tongnunui *et al*. (2007).

### 1.2 Habitat utilization

Fish communities in the mangrove forests often reflected in high diversity and abundance due to the variations in habitat heterogeneity for nursery and breeding grounds and food sources in these forests. Mangrove pneumatophores, prop roots, trunks and fallen branches and leaves make a complex habitat for fish. Physical structures as well as the environmental quality in the forest were also important in determining the structure and species composition of mangrove fish. Assessment of the value of mangrove forests to fish and ways in which fish utilize/dependent upon the mangrove, must be taken into account to determine the importance of such system to fish communities (Blaber, 1997). Table 2.4 summarized the habitat utilization of fish in Pak Phanang mangrove forest as revealed from this study and by comparisons with other reports.

**True mangrove resident species**

In this study, true resident species spending their entire life in the forests were fish in 10 families of Engraulidae, Clupeidae, Ambassidae, Leiognathidae, Gerreidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae and Cynoglossidae. These fish often small, numerous and numerically dominating the mangrove fish fauna (Blaber, 1977). These resident mangrove forest species can usually tolerate environmental variations such as salinity, pH and dissolved oxygen (Gilmore *et al*., 1982). Thus, most fish permanently resided in the mangrove forests have adaptations that allow them to survive the extreme physical characteristic of mangrove habitats such as low dissolved oxygen conditions and variable salinity regimes. (Halliday and Young, 1996; Satapoomin and Poovachiranon, 1997; Somkleeb *et al*., 2001).

Family Gobiidae is by far the most diverse family in the true resident group and have often been recorded as abundant in mangroves and estuaries in other geographical regions (Paphavasit *et al*., 2004; Lugendo *et al*., 2007; Tongnunui *et al*., 2007; Satapoomin and Karnchanaphaiharn, 2007). Euryhaline adaptations in gobiids allow them to be the major representative of resident brackishwater fish (Neira *et al*., 1998). These fish are known to breed intensively during the period of low salinity in the mangrove forests. Moreover these fish often with setting eggs attached to mangrove floors and among roots (Vatanachai, 1979a; UNDP/UNESCO, 1991). Mudskippers (*Periopthalmus cantonensis*) spend their whole life cycle, including breeding in or near mangroves. Female attach eggs with soft-substrate such as shells, macroalgae, dead tree or leaves in order to keep eggs and young away from strong water currents and tides. After hatching, planktonic larvae stay in the water column in a short period (Thresher, 1984).

Table 2.4 Habitat utilization in fish communities in Pak Phanang mangrove forests, Nakhon Si Thammarat Province based on different stages found in the mangroves and in comparison with other reports and http://www.fishbase.org/search.php.

| **No.** | **Family** | **Resident species** | **Partial residents** | **Marine migrants** |
|---|---|---|---|---|
| | | | **Nursery and feeding ground** | |
| 1 | Megalopidae | | | + |
| 2 | Engraulidae | + | | |
| 3 | Clupeidae | | + | |
| 4 | Bagridae | | | + |
| 5 | Ariidae | | | + |
| 6 | Plotosidae | | | + |
| 7 | Mugilidae | | | + |
| 8 | Atherinidae | | + | |
| 9 | Phallostethidae | | | + |
| 10 | Hemiramphidae | | | + |
| 11 | Aplocheilidae | | | + |
| 12 | Syngnathidae | | + | |
| 13 | Scorpaenidae | | | + |
| 14 | Ambassidae | + | | |
| 15 | Sillaginidae | | | + |
| 16 | Leiognathidae | + | | |
| 17 | Gerreidae | + | | |
| 18 | Sciaenidae | | | + |
| 19 | Callionymidae | | | + |
| 20 | Blenniidae | | + | |
| 21 | Eleotridae | + | | |
| 22 | Gobiidae | + | | |
| 23 | Scatophagidae | + | | |
| 24 | Siganidae | + | | |
| 25 | Sphyraenidae | | + | |
| 26 | Cynoglossidae | + | | |
| 27 | Tetraodontidae | | | + |

This was consistent to the findings of Blaber and Milton (1990) that Gobiidae dominated both in diversity and abundance on muddy bottoms, but less so on hard-bottom mangrove estuaries (in the Solomon Islands). It is noteworthy, that Gobiidae is often particularly abundant in tropical mangrove estuaries, including the Gulf of Thailand and Andaman Sea (Ikejima *et al*., 2003; Paphavasit *et al*., 2004; Wongchinvit *et al*., 2006). Tongnunui *et al*. (2007) observed that Gobiidae fish often limited their distribution in the mangrove plantations of more than 10 years of age in the Pak Phanang Estuary. Diversity of these fish was lower in degraded forest as compared to the natural forest. Satapoomin and Karnchanaphaiharn (2007) suggested from their study on fish assemblages in the mangrove plantations at Phuket Bay that in order to gain insight into the colonization and succession of fish in the mangrove plantation areas, the population study of small resident gobies should be concentrated. Significantly high abundance of these resident fish in the mangrove plantations may infer a level of success in colonization of these fish following a gradual establishment of environmental condition and microhabitats in the area.

Fish in the family Ambassidae were also dominant. They were euryhaline, found in shallow waters; common in estuaries; may enter lower reaches of rivers mainly in protected areas with overhanging or emergent vegetation such as mangroves. The Ambassidae gathers in aggregations sometimes quite large under shelter. At night, these fish become active and disperse as they feed. They feed mainly at night on crustaceans, but also take small fish, fish eggs and larvae in estuaries. The Ambassidae spawns with demersal eggs that were scattered on vegetations in freshwater, marine and brackishwater. Some may spawn with pelagic eggs. Most larvae were pelagic holding close to vegetations and roots as shelter (Conover, 1992).

Family Leiognathidae were also common along the shoreline and in estuaries (Blaber *et al*., 1995). The eggs of Leiognathidae species such as *Leiognathus equulus* were pelagic (Lee *et al*., 2005) and juveniles need to locate and enter estuaries without parental assistance. Juveniles of *Leiognathus equulus* and *L. splendens* live mainly in shallow, or shallow and vegetated areas in mangrove. This allows them to seek refuges from fish predation (Whitfield and Blaber, 1978). Juveniles of many other *Leiognathus* species are abundant offshore (Staunton-Smith *et al*., 1999). Some juveniles in the family Gerreidae such as *Gerres filamentosus* and *G. oyena* are estuarine dependent (Blaber *et al*., 1989).

Family Scatophagidae can be found widely distributed in the Pak Phanang Estuary. It can travel up rivers especially as juveniles. They are found in small creeks and waterways which the entire forest is always flooded by the high tides. The fish larvae would have the complete access to the intertidal mangrove zone during high tides. This will allow more feeding time and wide dispersal of young fish through the mangrove forests. Adult fish migrate to spawn in mangrove areas (Vatanachai, 1979a; UNDP/UNESCO, 1991; Janekarn, 1993; Tongnunui *et al*., 2002; Paphavasit *et al*., 2004).

**Partial resident species**

Partial residents seeking mangrove forest as nursery area and forage were Clupeidae, Atherinidae, Syngnathidae, Blenniidae and Sphyraenidae as in Table 2.4. Tidal connections to adjacent estuary transport biological production from the mangrove to the adjacent estuary and allowed recruitment to the mangrove of juvenile transient species that normally utilize this habitat as nursery habitats. When they reach juveniles, they start to swim out from the mangrove with the tidal fluctuation. The clupeids usually gathered for mating and distributed in coastal area. Afterward juveniles migrated into the mangrove area to seek shelter from predators. The most common transient omnivorous primary consumers are represented by Clupeidae (Gilmore and Snedaker, 1993).

The structure complexity of mangrove roots related both food and shelter from predators has been demonstrated by Thayer *et al*. (1987). Low numbers of large piscivore were also recorded in the mangrove of the Alligator and McIvor estuaries by Robertson and Duke (1987) and in the Trinity estuary by Blaber (1980). Similarly, in the Pagbilao Estuary in the Philippines, the most inland mangrove sites also lacked larger >100 mm carnivorous fish (Rönnbäck *et al*., 1999). The latter also compared the fish communities found among pneumatophores of *Avicennia officinalis* and in adjacent prop root habitats of *Rhizophora apiculata* in Philippines mangroves. The numbers, density and biomass of fish species were higher among the pneumatophores than in the prop root areas. This was because the limited height of pneumatophores allows a larger volume of water free of roots where fish can swim without encountering structural complexity.

There is evidence that the structure provided by the prop roots, pneumatophores and tree debris, as well as invertebrate burrows, in mangrove forests, provide small fish protection from predation by larger fish (Ley and McIvor, 2001). Moreover, the hydrology determines the availability of aquatic habitat for fish. Water level and salinity regimes can affect fish both directly through physiological responses and indirectly by altering the productivity of the mangroves themselves (Cintron *et al*., 1978). Food supply was the major factor inducing these fish to come into the mangrove proper and fringes. There is a greater supply of food for both adult and juvenile fish in mangroves and estuaries than in adjacent habitats.

### 1.3 Role of mangrove plantations as food sources for fish communities

#### Microphytoplankton

Mangrove forests, which are highly productive systems, have greater availability of food for fish than do other habitats, either directly as detritus or indirectly through the structural complexity attracting a greater number of food items. The average density of microphytoplankton ranged from $1.28 \times 10^3$ to $3.45 \times 10^4$ cells/l in high salinity and from $6.51 \times 10^3$ to $1.59 \times 10^5$ cells/l in low salinity period. Highest density of microphytoplankton was recorded at station PP3 (Klong Gong Kong) in low salinity period and at PP1 (Klong Bang Hua Koo) in high salinity period respectively (Figure 2.4). Generally, a rich epiflora of algae and diatoms is often found on the mangroves and associated substrata. Because mangrove usually occur in shallow intertidal areas of deposition, with quiet waters, muddy substrata, variable turbidities and a rich fauna and flora, their effects on fish are inextricably linked with these other factors (Blaber, 2000). Riley (1967) noted that the microphytoplankton of estuaries tends to be quantitatively abundant but limited as to the number of important species. The small number of species that can succeed in the variable estuarine environment leads to the dominance of those few. Over the whole year, many species appear in estuaries, but most of them are in small numbers and found at the mouth of the estuary. Very few species are always common.

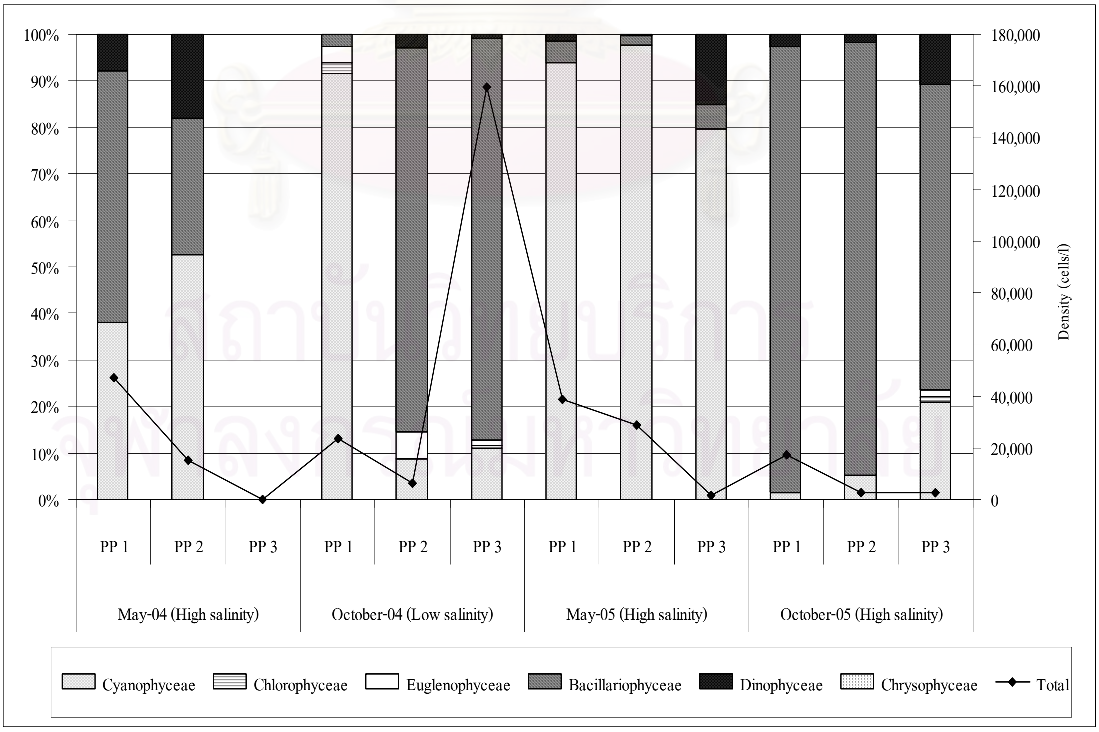



Figure 2.4 Density of microphytoplankton in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

During in high salinity periods, Cyanophyceae, cyanobacteria, comprised approximately 60% of total microphytoplankton density while Bacillariophyceae, diatoms, comprised more than 30% of total microphytoplankton density. During low salinity period, diatoms comprised more than 70% of total microphytoplankton density where Cyanophyceae declined to approximately 20% of total microphytoplankton density. The most dominant and most frequent were the Bacillariophyceae and Cyanophyceae particularly the genus *Nitzschia*, *Gyrosigma/Pleurosigma* and *Oscillatoria* respectively. The result showed the dominant groups and density of microphytoplankton corresponded with Piumsomboon *et al.* (2004). Bacillariophyceae and Cyanophyceae were also the dominant groups in Pak Phanang River and in the mangrove plantations on the eastern coast of Pak Phanang Estuary. Diatoms contributed more than 75% of total microphytoplankton abundance. In Pak Poon Estuary, high density of microphytoplankton recorded in the natural forest and the mudflat area. The most dominant and most frequent microphytoplankton were the diatom particularly the genus *Thalassiosira*, *Pleurosigma*, *Skeletonema* and *Nitzschia* (Piumsomboon *et al*., 2000).

**Zooplankton**

Zooplankton community in Pak Phanang Estuary in size >103 µm comprised of 11 phyla namely Protozoa, Cnidaria, Ctenophora, Plathehelminthes, Annelida, Rotifera, Chaetognatha, Arthropoda, Mollusca, Echinodermata and Chordata (Figure 2.5). During high salinity period, the average density of zooplankton varied from $4.02x10^6$ to $5.83x10^6$ individuals/100 $m^3$. The density of zooplankton varied from $9.04x10^6$ to $1.39x10^7$ individuals/100 $m^3$ during high salinity period with the maximum density in station PP1 (Klong Bang Hua Koo). During low salinity period, the density of zooplankton varied from $1.83x10^6$ to $1.02x10^7$ individuals/100 $m^3$ with the highest density in station PP2 (Klong Bang Luk). The majority of zooplankton in three mangrove plantations was the holoplanktonic component namely copepod nauplii, calanoid copepod, cyclopoid copepod and rotifer. In general, zooplankton community was dominated by arthropod crustaceans in particular copepods which contributed more than 60% of the total zooplankton density. The second most abundance zooplankton was crustacean nauplii consisted of brachyuran larvae, larvae of shrimps and barnacle larvae which play an important role in the pelagic food chain. Mysid, sergestids, rotifers, gastropod larvae were also common in the area.

The density of zooplankton in size >330 µm comprised of 10 phyla namely Protozoa, Cnidaria, Ctenophora, Nematoda, Annelida, Rotifera, Chaetognatha, Arthropoda, Mollusca and Chordata. The average density of zooplankton varied from $1.28x10^4$ to $4.26x10^4$ individuals/100 $m^3$. The density varied from $4.17x10^4$ to $1.20x10^5$ individuals/100 $m^3$ during high salinity period with highest density at station PP1 (Klong Bang Hua Koo). During low salinity period, the density of zooplankton varied from $9.50x10^2$ to $3.73x10^5$ individuals/100 $m^3$ with the highest density in PP3 (Klong Gong Kong). The dominant groups were copepod nauplii, calanoid copepod and brachyuran larvae (Figure 2.6). In addition, shrimp larvae, bivalve larvae, gastropod larvae, lucifer and larvacean were common.

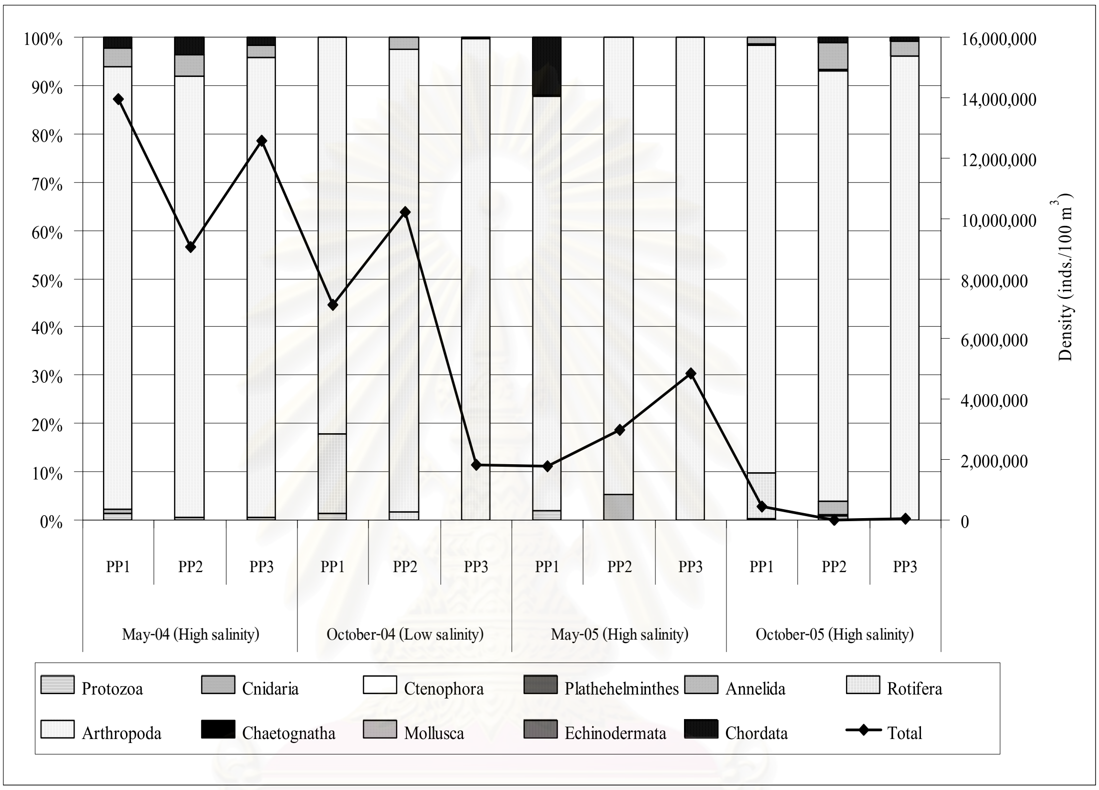



Figure 2.5 Density of zooplankton >103 micrometer in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

Zooplankton community in Pak Phanang mangrove forest comprised of the common members in the coastal areas of Thailand such as the Pak Poon Estuary, Outer Songkhla Lake, Klong Kone mangrove swamp and Bandon Bay (Angsupanich and Aruga, 1994; Piumsomboon *et al*., 1999a; Piumsomboon *et al*., 1999b; Piumsomboon *et al*., 2004). Copepoda and nauplius larvae were the most abundant zooplankton in this area. The density of zooplankton from this study was also in the same range as in Pak Poon Estuary, Outer Songkhla Lake and Bandon Bay, Surat Thani Province (Angsupanich and Aruga, 1994; Piumsomboon *et al*., 1999b; Piumsomboon *et al*., 2004). High density of zooplankton of both sizes in high and low salinity period appeared in the stations with high microphytoplankton density.

Calanoid copepod and nauplii were the important herbivore in pelagic community. Besides these crustaceans, barnacle larvae, brachyuran larvae and mollusc larvae were also the herbivorous zooplankton. During low salinity period, the second most abundant zooplankton was the rotifer as another major herbivorous group. The occurrence of rotifers corresponded with the low salinity period. Chaetognath was the major carnivorous zooplankton distributed at all stations throughout the sampling period. Another zooplankton was the larvaceans found in abundance in the high salinity period (23.2-33.1 psu) in comparison to the low salinity period (2.3-5.6 psu). These larvaceans are one of the important zooplankton due to their feeding on pico- and nanophytoplantkon and their rapid growth rates (Hopcroft *et al*., 1998). The major planktonic omnivore found in Pak Phanang mangrove forest was the mysids which consumed both microphytoplankton and zooplankton.

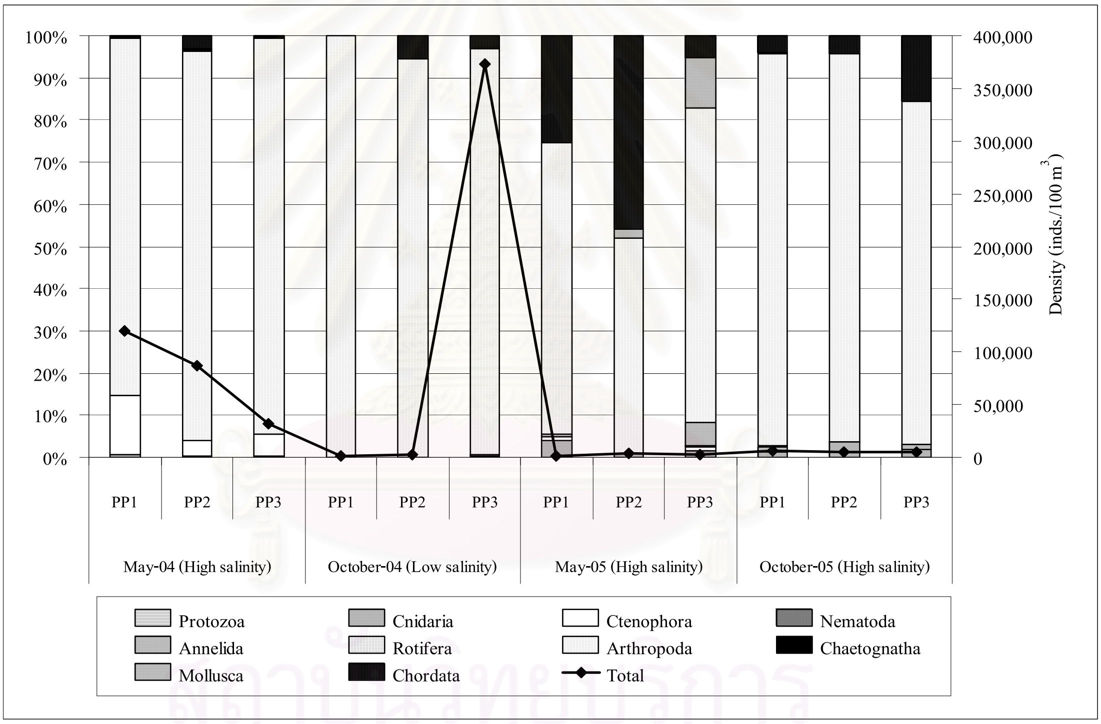



Figure 2.6 Density of zooplankton >330 micrometer in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

**Benthos composition and sediment characteristics**

Mangrove plantations in the Pak Phanang Estuary have developed more than 20 years olds similar to the natural mangrove forests. Sediment composition as clay, silt and sand particle in mangrove plantations of different age did not show significant difference between high and low salinity period respectively ($p$>0.05). The average clay particle was 14.33-21.91% in high salinity

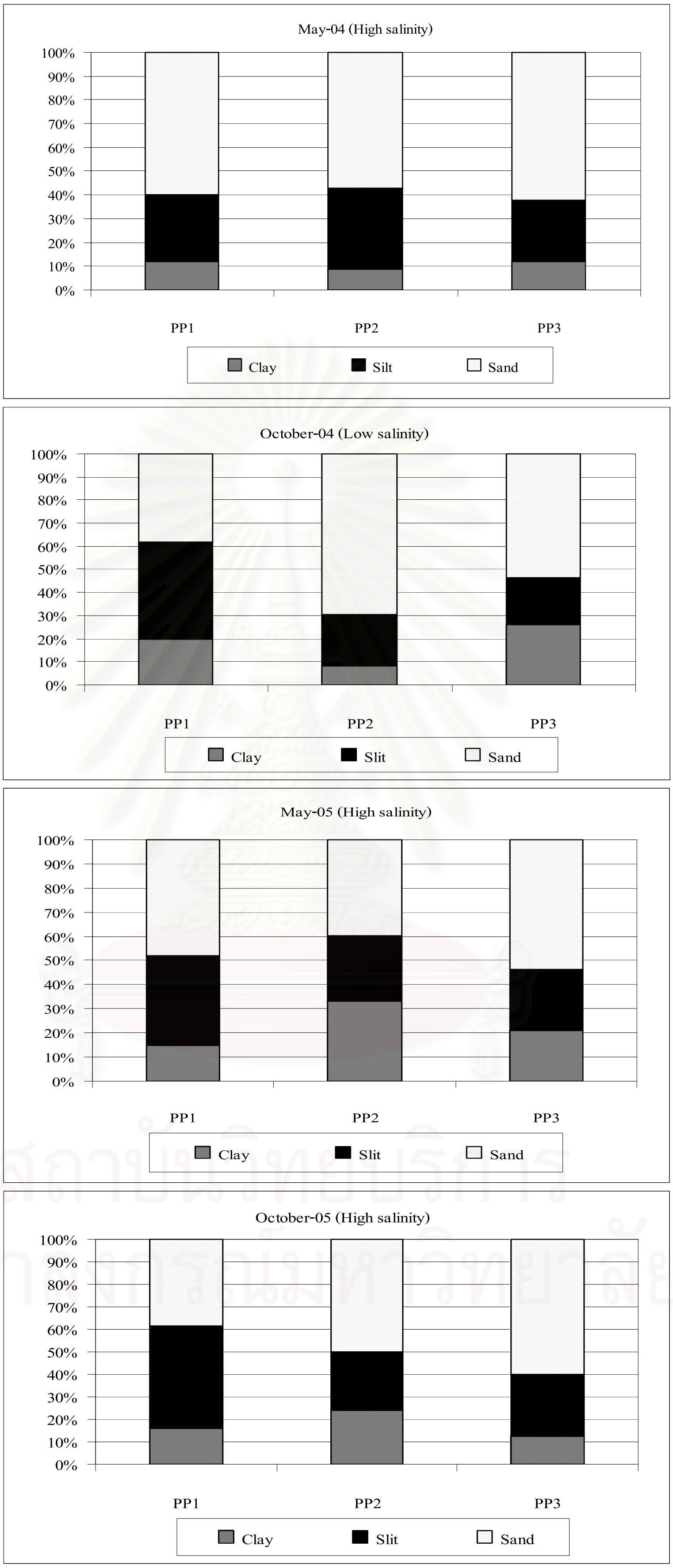



Figure 2.7 Grain size in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

period and 8.36-26.00% in low salinity period. Silt particle was on the average of 26.19-36.93% and 20.14-69.64% during high and low salinity respectively. The average sand particle in high salinity was 48.74-58.57% and 22.00-53.85% in low salinity (Figure 2.7).

The average organic matter content were 13.59-31.30% in high salinity period and 10.48-24.48% in low salinity period. Organic matter content did not show different significantly between high and low salinity ($p$>0.05) as in Figure 2.8. High organic content in sediment recorded corresponded to the high organic detritus. Organic detritus in form of underground, pneumatophore and seedling biomass in the mangrove plantations of Pak Phanang Estuary was on the average of 443.06 g/$m^2$ (Figure 2.9) as compared to the natural mangrove forests in Baan Klong Kone, Samut Songkhram Province of 352.97 g/$m^2$ (Wichitwarakhun *et al*., 2002). Dense tree canopy in the mangrove plantations contributed to this high organic detritus in term of forest biomass as the mangrove plantation aged. Theses organic detritus in turn will become the important food sources for aquatic species.

Low diversity of benthos recorded in the mangrove plantations of Pak Phanang Estuary as previously reported by Paphavasit *et al*. (2004). Gastropods, polychaetes and insect larvae were the dominant groups. Paphavasit *et al*. (2004) also found that polychaetes comprised more than 55% in the mangrove plantations at station PP1 (Klong Bang Hua Koo) and decreased to 35 and 30% at station PP2 (Klong Bang Luk) and station PP3 (Klong Gong Kong) respectively. Small red gastropod, *Assiminea brevicula* and other gastropods such as *Telescopium telescopium* and *Cerithidea cingulata* as well as nematodes were common at all stations. Low diversity of benthos recorded in the area in contrast to the dense mangrove plantations of different age. This was due to the hypoxia condition in the Pak Phanang Bay and in the mangrove forests. Hypoxia condition in the area resulted from human activities in term of shrimp farmings and urbanization. Conversion of mangrove forests to shrimp farms, not only lead to degraded mangroves, but also change the hydrology of the area and increase sedimentation from shrimp farm effluents. Moreover the sedimentation rate in the Pak Phanang Estuary was quite rapid thus the exchange rate between the estuary and coastal seas affected. Although the mangrove reforestation has been carried out since 1982, but the mangrove plantations were not maintained according to the silviculture technique to promote production. Thinning and pruning have not been carried out. In the long term, even with high forest biomass as the mangrove plantation aged, but these hypoxia conditions are not suitable for benthos and fish. The availability of habitats and food sources will soon be lost.

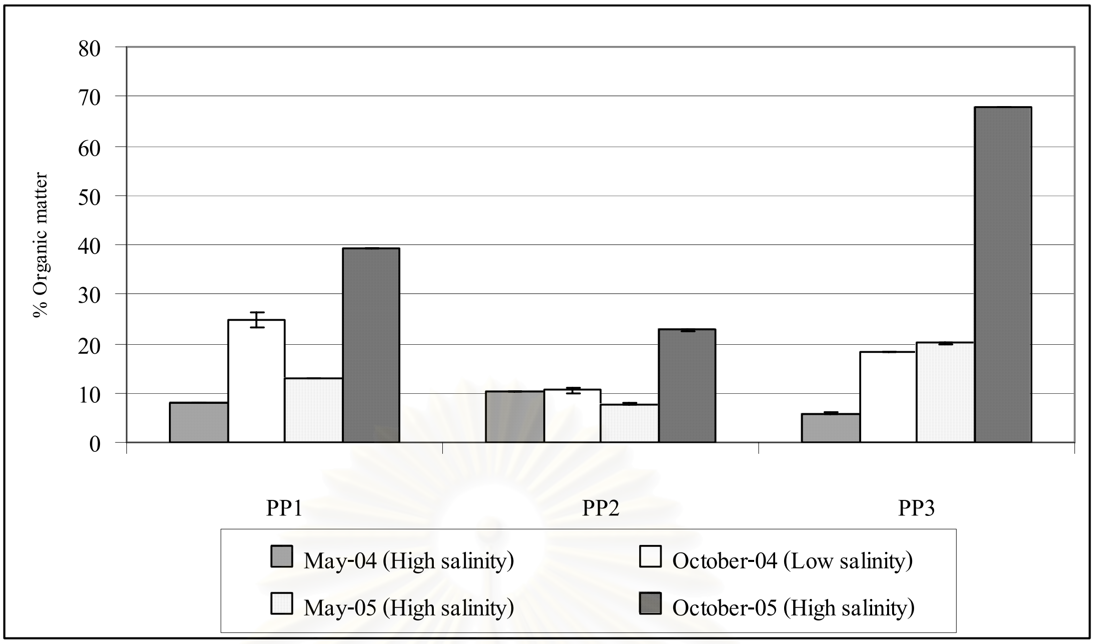



Figure 2.8 Organic content in sediment (Mean±SE) in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

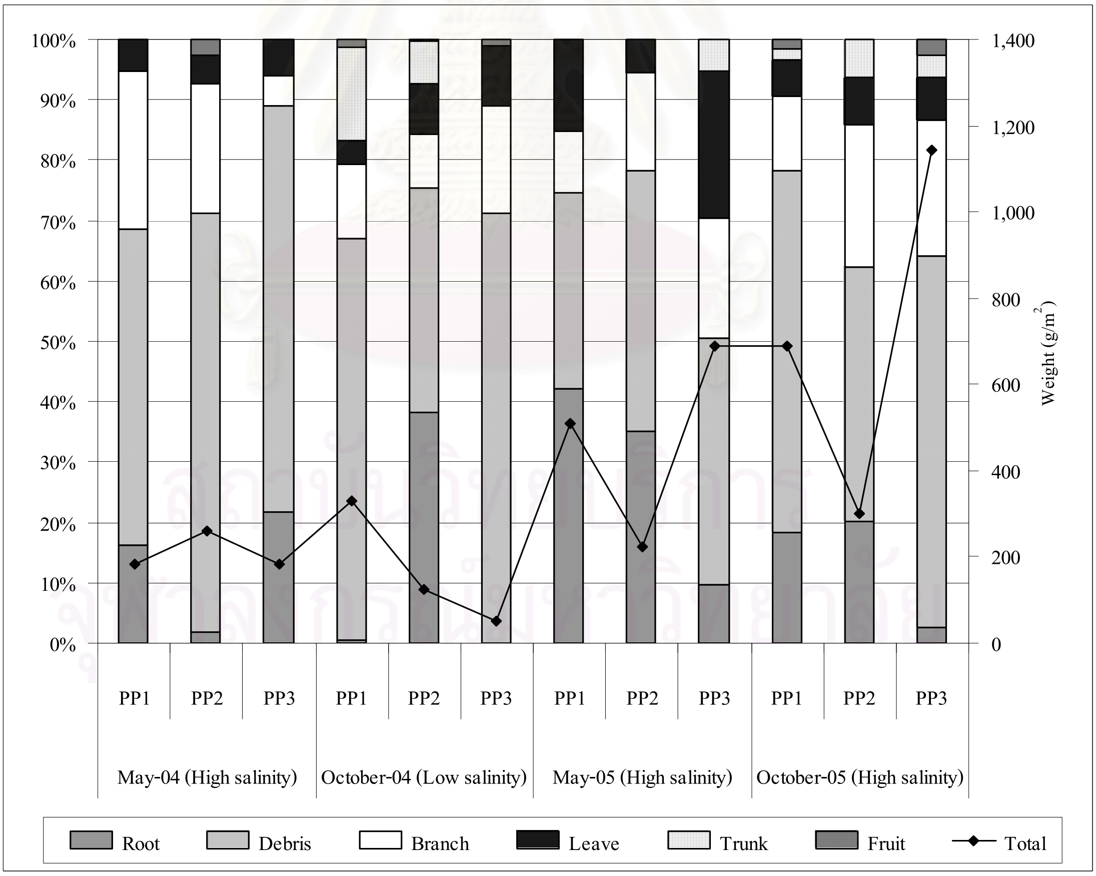



Figure 2.9 Total forest biomass in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

### 1.4 Feeding types in fish communities in Pak Phanang Estuary

Marine migrants move into the mangrove on tide currents and use mangrove forests as feeding ground in short period, as occasional visitors (Barreiros *et al*., 2004). Marine migrants in the Pak Phanang mangrove forest were fish in the family Megalopidae, Bragidae, Ariidae, Plotosidae, Mugilidae, Phallostethidae, Hemiramphidae, Aplocheilidae, Scorpaenidae, Sillaginidae, Sciaenidae, Callionymidae and Tetraodontidae as shown in Table 2.4. Large juveniles and mature adults will periodically visit tidal fringe mangrove forest habitats, river and creeks where adequate prey and water depth allow at high tide and leave on the ebbing tide. Moreover, they may be foraging for food, seeking protection from predation or simply being passively carried by the tidal. Important food items for juveniles included fish, shrimp and microcrustacean (Luczkovitch *et al*., 1995). Large species such as *Lutjanus argentimaculatus* also enter the forest at high tide, in search of food. In the Embley Estuary in the Gulf of Carpentaria, most fish were benthic invertebrate feeders with very few were piscivore (Blaber *et al*., 1989). In the Benin Estuarine, the mangrove fish community was numerically dominated by detritivore (39.4%) and planktinovore/microcarnivore (45.6%). Though not numerically important, the intermediate carnivore (4.7%) and the top predators (6.6%) comprised a relatively high species number, while herbivore species comprised 3.7% (Adite, 2002). In the Tin can Bay of Australia, detritivore and planktinovore/microcarnivore were numerically among the major trophic categories (Halliday and Young, 1996). In the Moreton Bay, detritivore consistently dominated the fish communities. This similarity of trophic structure probably results from an evolution of the mangrove fish communities with the available food. Fish have evolved to better exploit the organic detritus in form of litter falls. In contrast, in term of abundance, top predators tend to be reduced even though the number of species seems to be relatively high.

Therefore, there is a greater supply of food for both adult and juvenile fish in estuaries than in adjacent habitats. Many of the prey types are found only within estuaries and may obligate links with mangrove. Also, any estuarine food depending on the fish may not only relate to the larger quantity of food but to its greater diversity and the availability of wider size ranges than occur in adjacent water. The latter is particularly important because during their relatively rapid growth the post-larvae and juveniles of most species must go through sequential ontogenetic changes in the size of food taken.

Table 2.5 and Figure 2.10 showed the feeding types in fish communities in the Pak Phanang Estuary. The result of correlation analysis between fish abundance and food sources in the mangrove showed that the fish abundance closely correlated to the zooplankton density.

Zooplankton feeders in the area were more than 35% while 39% were benthic feeder. The microphytoplankton was also related with zooplankton because species composition, density and size distribution of microphytoplankton were controlled by zooplankton. Microphytoplankton and zooplankton are important food for fish larvae and juveniles, indicating an overall net benefit in selecting the mangrove habitat. Furthermore, zooplankton is the main food source for the larvae and fry found in estuaries elsewhere (Bennett, 1989). Thus, zooplankton in large numbers is an important food source for planktivorous fish.

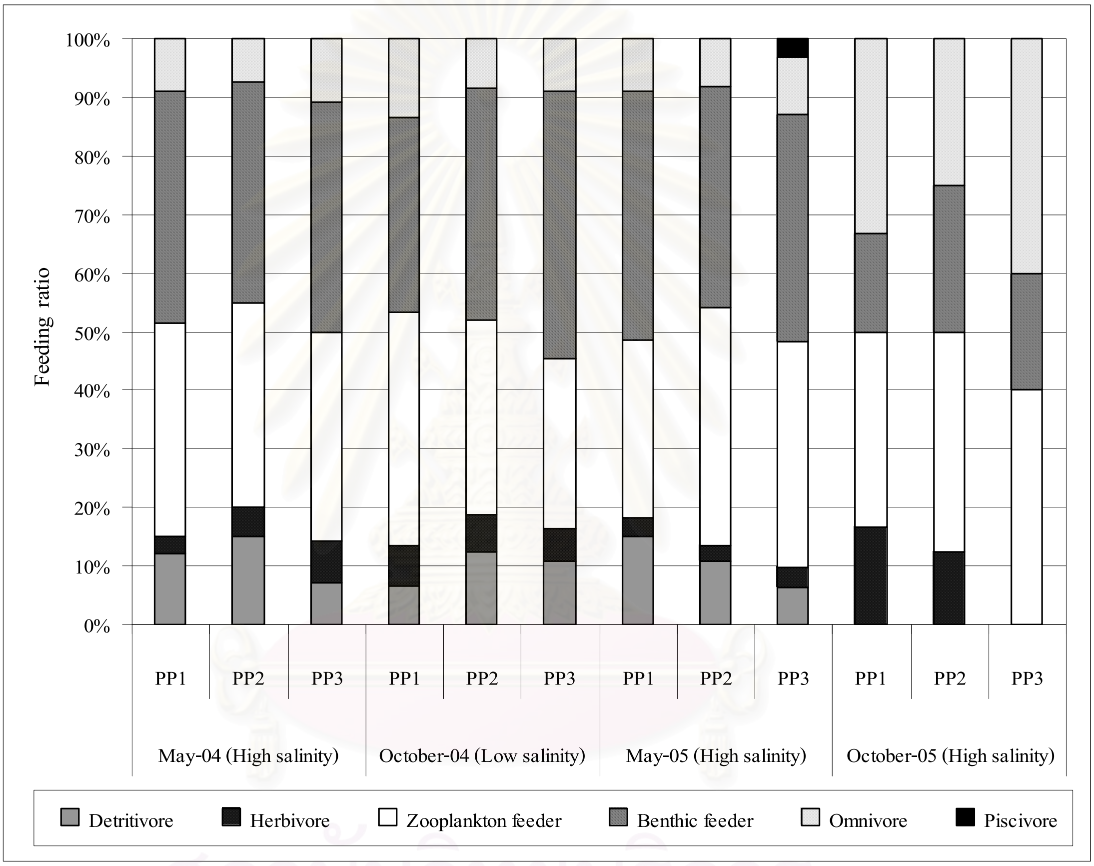



Figure 2.10 Feeding types of fish in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

Table 2.5 Feeding types of fish in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

| No. | Family | Feeding types | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Detritivore** | **Herbivore** | **Zooplankton feeder** | **Benthic feeder** | **Omnivore** | **Piscivore** |
| 1 | Megalopidae | | | | * | | |
| 2 | Engraulidae | | | * | | | |
| 3 | Clupeidae | | | * | | * | |
| 4 | Bagridae | | | | * | | |
| 5 | Ariidae | | | | | | * |
| 6 | Plotosidae | | | | | | * |
| 7 | Mugilidae | | * | | | | |
| 8 | Atherinidae | | | * | | | |
| 9 | Phallostethidae | | | * | | | |
| 10 | Hemiramphidae | | | * | | | |
| 11 | Aplocheilidae | | | * | | | |
| 12 | Syngnathidae | | | * | | | |
| 13 | Scorpaenidae | | | | * | | |
| 14 | Ambassidae | | | * | * | | |
| 15 | Silaginidae | | | | * | | |
| 16 | Leiognathidae | * | | | * | | |
| 17 | Gerreidae | | | | * | | |
| 18 | Sciaenidae | | | | * | * | |
| 19 | Callionymidae | | | | * | | |
| 20 | Blenniidae | | | * | | | |
| 21 | Eleotridae | * | | | * | | |
| 22 | Gobiidae | * | | * | * | | |
| 23 | Scatophagidae | | | | | * | |
| 24 | Siganidae | | * | | | | |
| 25 | Sphyraenidae | | | * | | | |
| 26 | Cynoglosidae | * | | | * | | |
| 27 | Tetraodontidae | | | | | * | |

**1.5 Factors determining the distribution and abundances in fish communities in the Pak Phanang mangrove forests**

The environmental parameters showed distinctly difference on salinity and dissolved oxygen during low and high salinity ($p$<0.05). The average salinity in May 2004, May 2005 and October 2005 were 27.62 psu showed distinctly difference from October 2004 3.78 psu. Dissolved oxygen showed significantly difference between high and low salinity period ($p$<0.05). During low salinity period dissolved oxygen recorded at 2.66 mg/l and 4.40 mg/l in high salinity period. Dissolved oxygen decreased in low salinity period due to flooding of runoffs from the opening of the regulators inorder to control flood. Heavy rains also contributed to high turbidity during this period. High density of organic matter was detected. These contributed to low oxygen during the low salinity period (Table 2.6 and Figure 2.11).

Table 2.6 Environmental parameters between high and low salinity period in Pak Phanang mangrove forests, Nakhon Si Thammarat Province

| Environmental parameters | Low salinity (Mean ± SE) | High salinity (Mean ± SE) |
|---|---|---|
| Salinity (psu) | 3.78±0.97 | 27.62±1.08 |
| Temperature ($^{o}$C) | 28.45±0.45 | 29.81±0.24 |
| Dissolved Oxygen (mg./l) | 2.27±0.40 | 4.61±0.35 |
| pH | 7.03±0.03 | 7.44 ±0.11 |
| Transparency (m.) | 0.26 ±0.03 | 0.31±0.03 |
| Water depth (m.) | 1.13±0.18 | 1.55±0.37 |

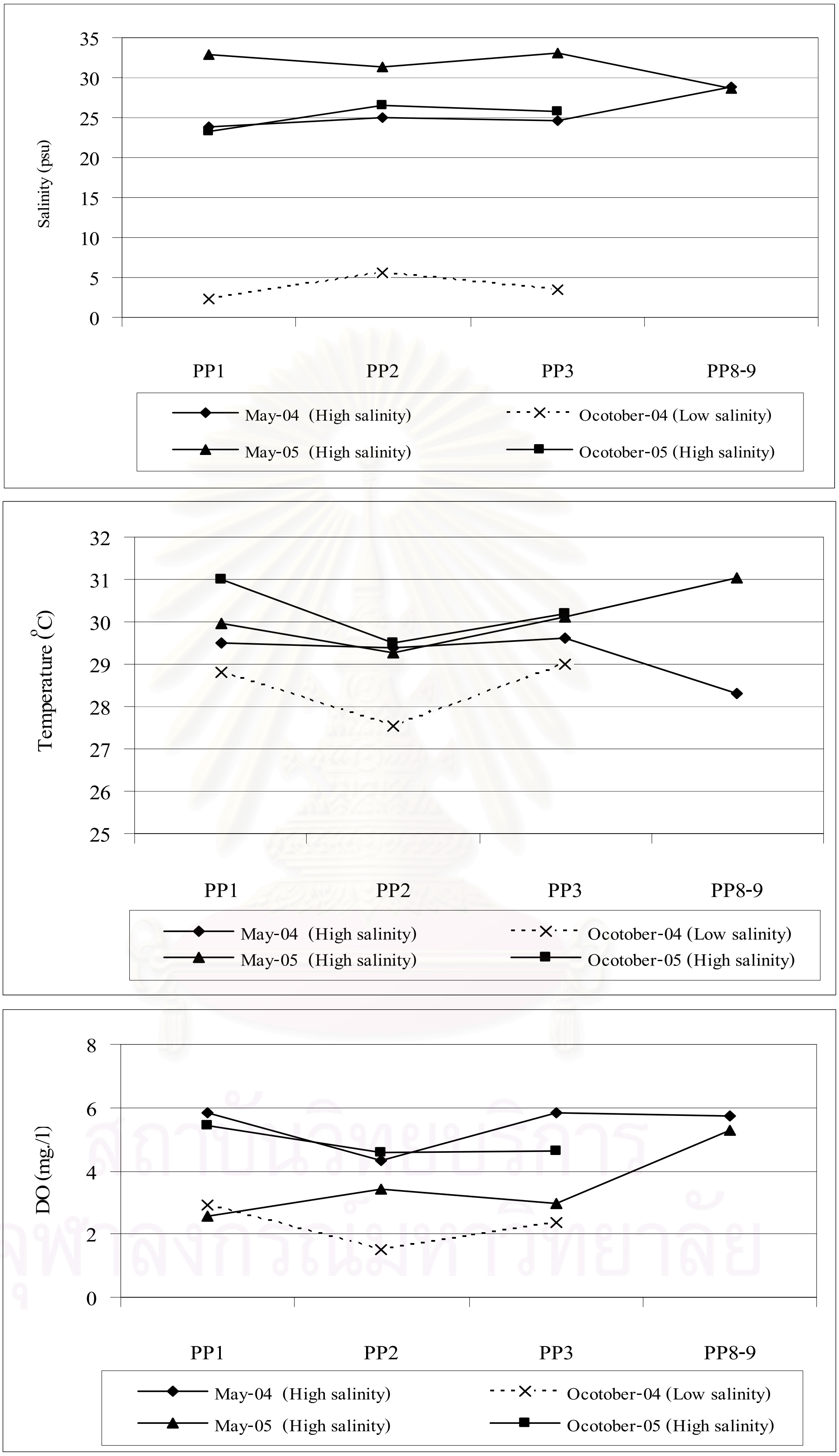
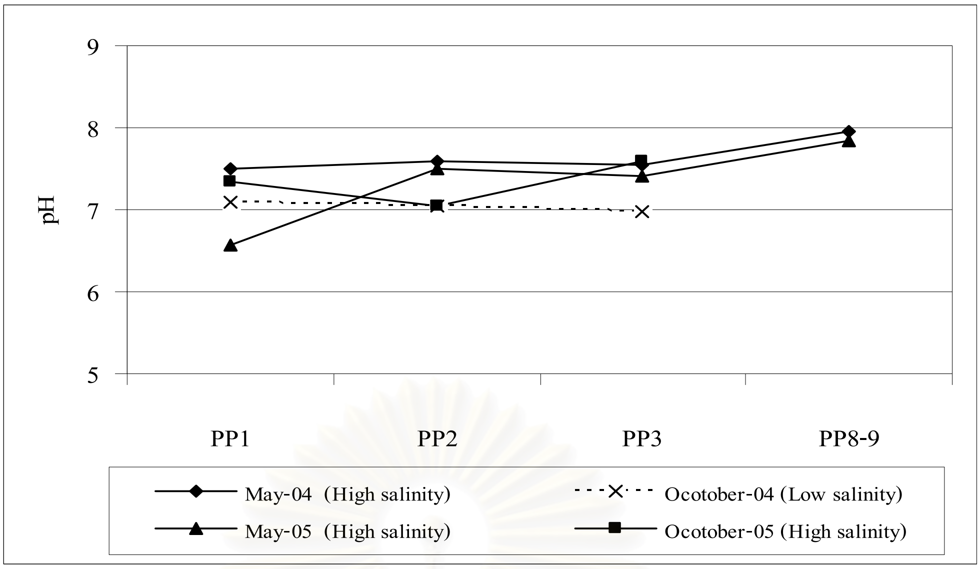
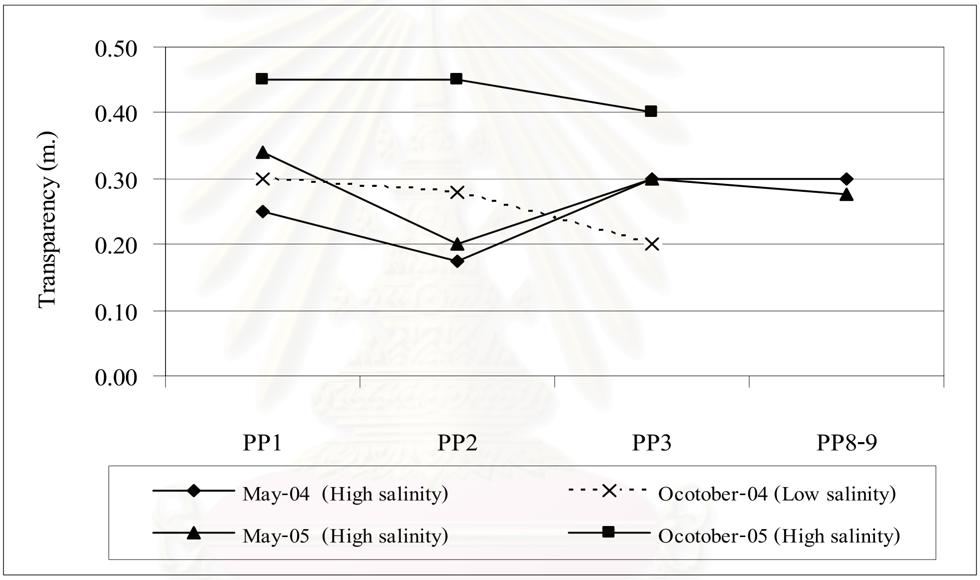



Figure 2.11 Environmental parameters in each station during collection period in Pak Phanang mangrove forests, Nakhon Si Thammarat Province



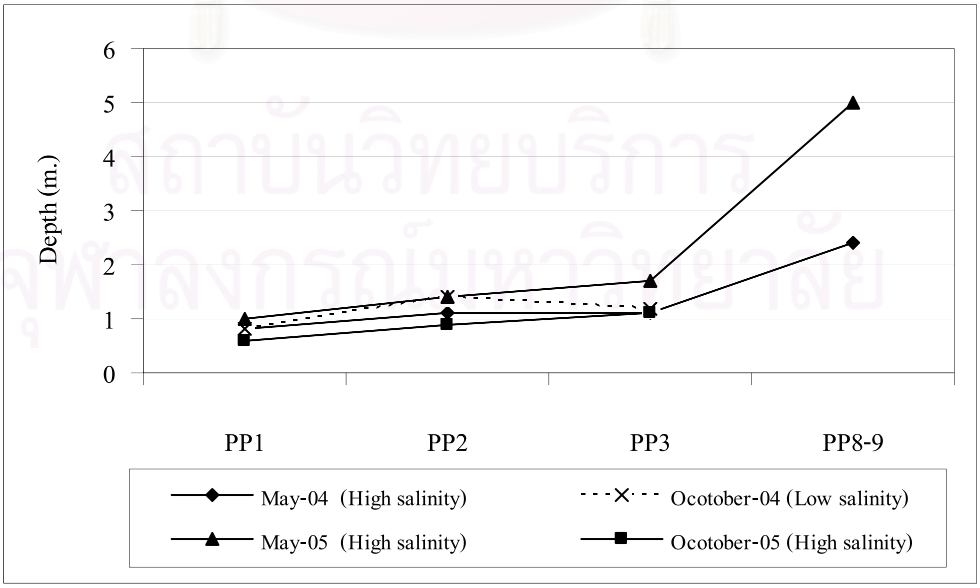




Figure 2.11 (Continued)

Factors determining the abundance in fish communities with environmental parameters and food sources during the high and low salinity periods in the Pak Phanang mangrove forests were tested by using the Pearson Correlation analysis in Table 2.7. Salinity, temperature and organic detritus as total forest biomass showed the inversed relationship with the larval density. High density of fish larvae correlated to high microphytoplankton, zooplankton in size >103 μm density. Generally, as the environmental condition change according to seasons, the suitability of the environment for the vulnerable early life history stages will vary. Fish reproduce at time of year that will tend to maximize its lifetime production of offspring (Wootton, 1999).The results showed larval families of Ambassidae, Blenniidae and Gobiidae have the highest density in low salinity (wet season). In addition, family Gobiidae was mostly typical brackishwater fish as resident species in this area and other mangrove forests which their intensive breeding in the wet season or low salinity (UNDP/UNESCO, 1991; Termvidchakorn and Paphavasit, 1999). This condition for egg development and larval survival are suitable including food source. The density of fish larvae was correlated with biomass of zooplankton available as food for the larvae during low salinity. However, the high temperature can occur in shallow water area, fish larvae can suffer considerable mortality if trapped in inter-tidal pools and that such mortality can be attributed directly to lethal high temperatures and the damaging effect of ultraviolet radiation (Elliott and Hemingway, 2002). Moreover Klong Gong Kong (PP3) high accumulation of organic detritus in term of total forest biomass due to dense tree conopy in the mangrove plantation revealed low dissolved oxygen and sulfide concentrations as in. These conditions were not suitable habitat for larvae density.

Juvenile density showed inversed relationship with temperature, transparency and organic detritus as total forest biomass. High density of juvenile correlated to high microphytoplankton, zooplankton in size >103 μm density. Distribution and density of juveniles correlated with temperature changes due to direct effect on fish metabolism unless mechanisms for evading these pervasive effects have evolved (Brett and Groves, 1979).Moreover, temperature, not only affect the rate of metabolism but also on the rates of feeding, growth and reproductive activities. Fish usually detect the temperature gradient in the water. This allows them to exert some behavioral control over their body temperature by selecting the optimal temperature to live in. In term of protection, turbidity provided juvenile fish with a form of cover through a reduction in light intensity, visually obscuring prey species from their predators. Adults of many piscivorous fish such as carangids and sphyraenids were visual feeders and occurred mainly in clear water. In turbid waters they would have to get much closer to their prey before attacking and the prey could elude capture (Hecht and van der Lingen, 1992). Thus, juvenile fish often inhabit in mangrove creek where turbid water, shallow waters excluded large fish. The structural complexity of mangrove such as prop roots and pneumatophores also enabled small fish to hide from predators while providing more food supply for juveniles (Blaber, 2000). Furthermore, the density of juvenile fish increased according to the important food source, zooplankton. Arthropod crustaceans in particular copepods were major food sources. Beside the increase in organic detritus in term of forest biomass as the mangrove plantation aged was evidenced. These organic detritus in turn will become the important food sources for aquatic species. Benthos were also the important food source of juvenile and adult fish. However as revealed from this study, low diversity of benthos recorded in the area due to high total forest biomass creating the hypoxia condition with sulfide in the sediment. In the long term, even with high forest biomass as the mangrove plantation aged, but these sulfide and hypoxia condition are not suitable for juvenile and adult fish. The availability of habitats and food sources will soon be lost.

Table 2.7 Pearson Correlation test between environmental parameters and food sources with density of fish during high and low salinity periods

| Environmental parameters and food sources | Density of fish | | |
|---|---|---|---|
| | **Fish larvae** | **Juveniles** | **Adults** |
| Salinity (psu) | -0.515* | -0.255 | -0.422 |
| Temperature ($^{o}$C) | -0.546* | -0.528* | -0.052 |
| Dissolved Oxygen (mg./l) | -0.076 | -0.214 | -0.301 |
| pH | 0.038 | -0.044 | -0.074 |
| Transparency (m.) | -0.484 | -0.801* | -0.114 |
| Water depth (m.) | -0.108 | 0.080 | -0.215 |
| Microphytoplankton (cell/l.) | 0.597* | 0.636* | 0.232 |
| Zooplankton in size >103 µm (inds./100m$^{3}$) | 0.789* | 0.811* | -0.101 |
| Zooplankton in size >330 µm (inds./100m$^{3}$) | 0.245 | 0.403 | 0.472 |
| Organic detritus as total forest biomass (g/m$^{2}$) | -0.554* | -0.617* | -0.809* |

Remark: * Correlation is significant at 0.05 level (1-tailed)

### 2. Abundance and Distribution of *Scatophagus argus* in Pak Phanang Estuary

#### 2.1 Temporal and spatial distribution

The density of spotted scat in the Pak Phanang mangrove forests were shown in Figure 2.12-2.15. The total catches of larvae were 229 individuals/100 $m^3$. The average density of larvae in high salinity period was 24 individuals/100 $m^3$ while in low salinity period was 12 individuals/100 $m^3$. The highest density of fish larvae was recorded in station PP2 (Klong Bang Luk) during high salinity period. The total density of juvenile fish was 206 individuals. The average density of juveniles in high salinity period was 19 individuals and 12 individuals in low salinity period. The highest density of juvenile fish was recorded at station PP1 (Klong Bang Hua Koo) during high salinity period. The total numbers of adult fish were 224 individuals. The average density of adults was 12 individuals/100 $m^3$ in high salinity period and 40 individuals in low salinity period. The larvae and juvenile spotted scat limited their distribution in the mangrove forests while the adults distributed in the mangrove forests, inside the bay and coastal area.

From the distribution pattern in spotted scat community clearly showed the high abundance of larvae in Pak Phanang mangrove forest demonstrating the important of mangroves for nursery ground and food sources for this species. This finding corresponded to other tropical mangrove and estuaries such as mangrove estuary of the Tanshui River Estuary, Taiwan (Tzeng and Wang, 1992), mangrove forest in northern Australia (Vance *et al*., 1996), Negombo Estuary, Sri Lanka (Pinto and Punchihewa, 1996). Spotted scat often time their spawning periods with the occurrence of the first floods, ensuring a productive and protective habitat and thus a greater survival rate for their young. Thus, spotted scat utilized structural complexity in mangrove forest such as root systems, tidal channels and mangrove creeks, to provide shelters and refuges from predation in larval and juvenile stages (Janekarn and Boonruang, 1986). In addition, turbidity help reduced visibility of predation by large fish. Mangrove forests supply the enormous and continuous amount of food source is appropriated for juvenile fish in order to support their high rate of metabolism and growth. As fish grow a shift in habitat from mangroves to adjacent mudflat is a response to changes in diet, foraging efficiency and vulnerability to predators (Wootton, 1992; Whitfield, 1998; Blaber, 2000).

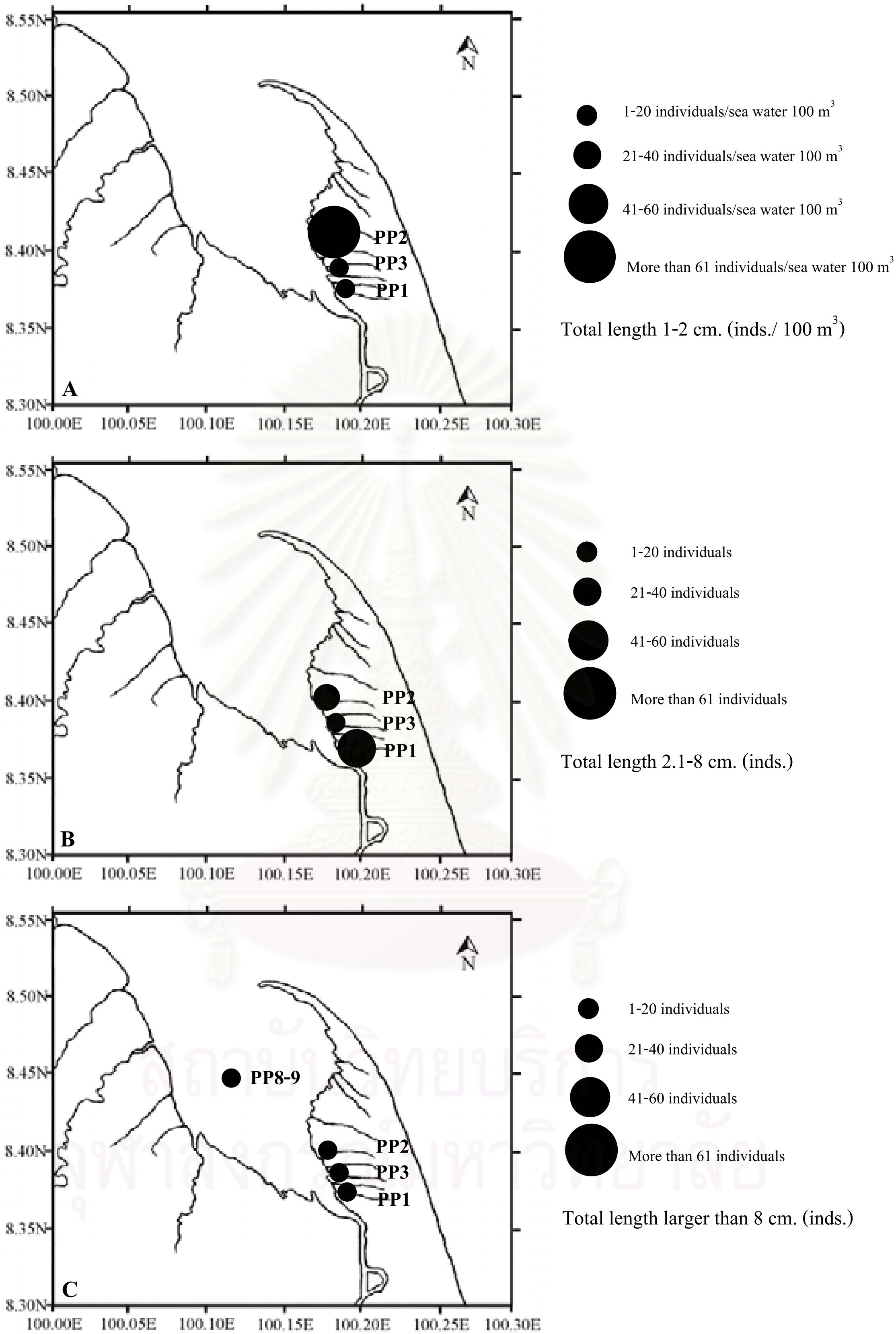



Figure 2.12 Distribution pattern of *Scatophagus argus* during high salinity 2004, May 2004 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province (Larvae (A), Juveniles (B) and Adults (C))

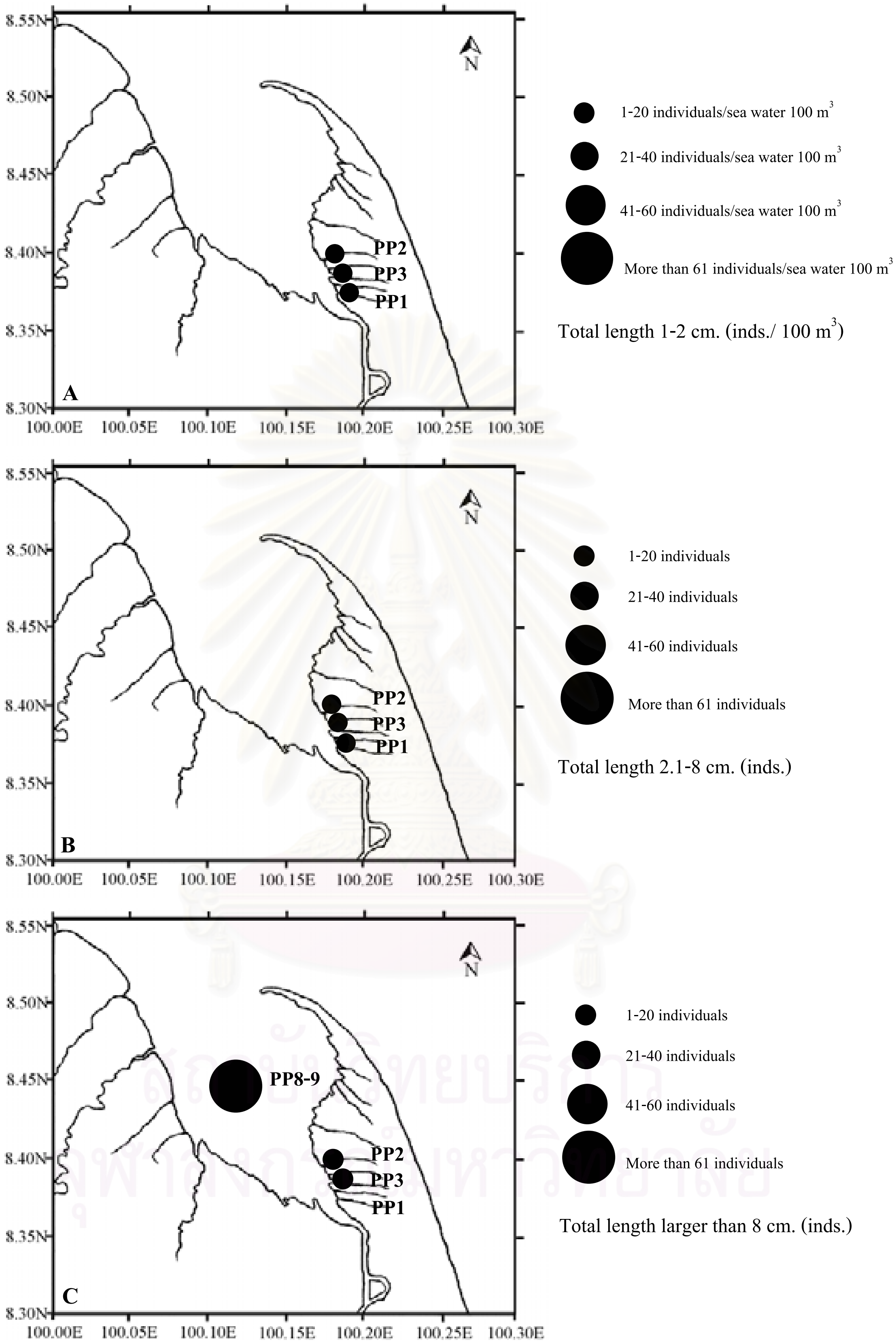



Figure 2.13 Distribution pattern of *Scatophagus argus* during low salinity 2004, October 2004 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province (Larvae (A), Juveniles (B) and Adults (C))

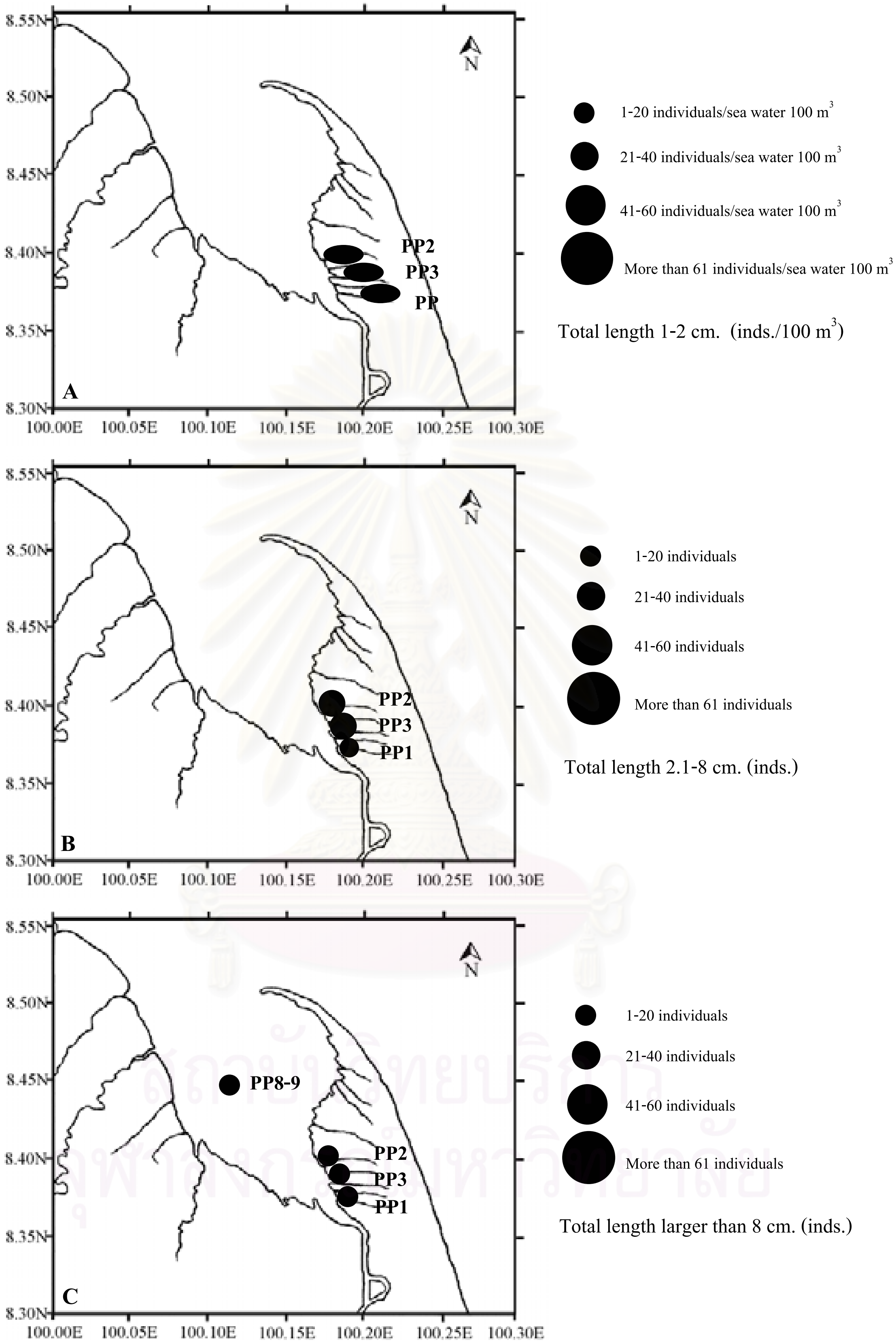



Figure 2.14 Distribution pattern of *Scatophagus argus* during high salinity 2005, May 2005 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province (Larvae (A), Juveniles (B) and Adults (C))

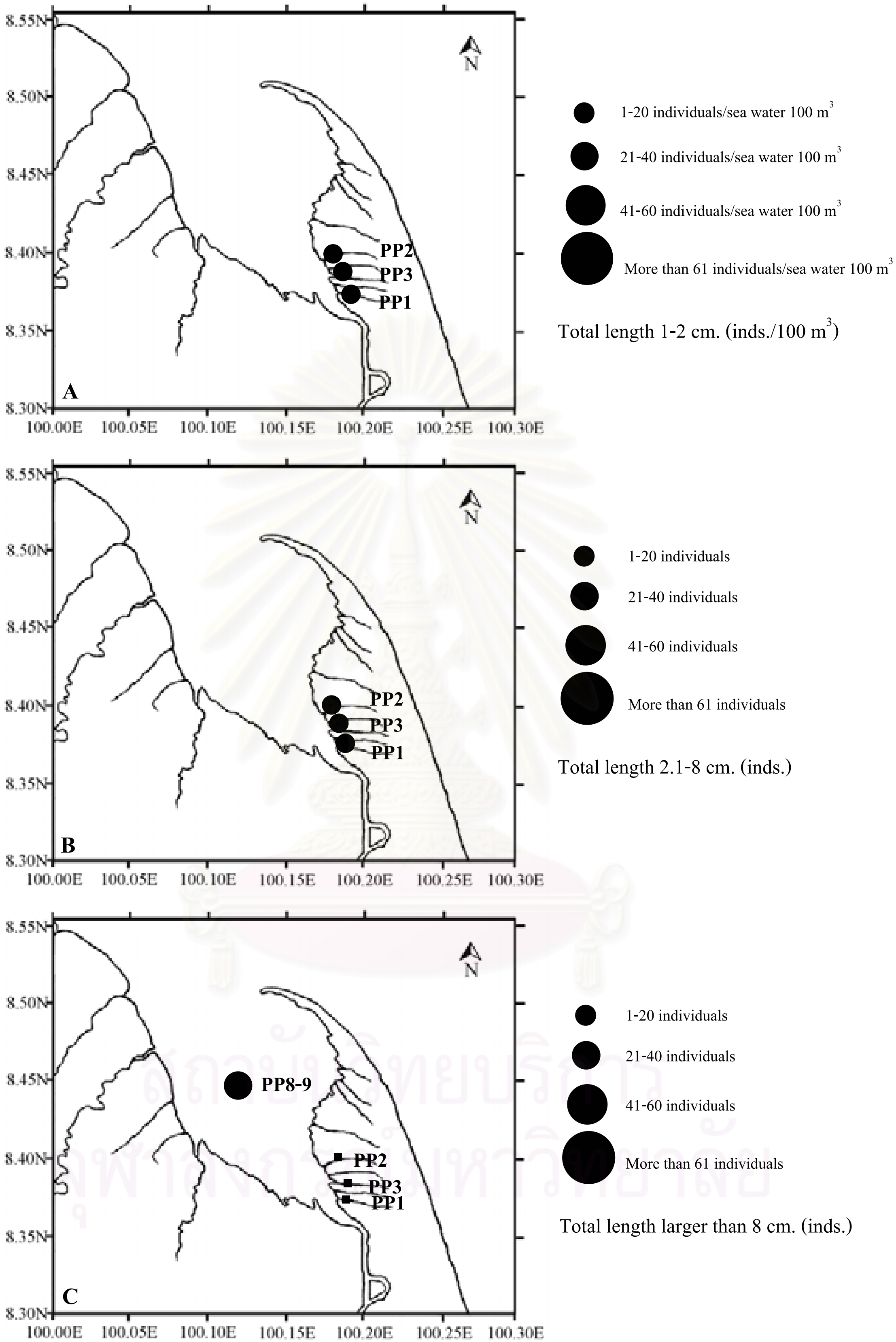



Figure 2.15 Distribution pattern of *Scatophagus argus* during high salinity 2005, October 2005 in Pak Phanang Mangrove forests, Nakhon Si Thammarat Province (Larvae (A), Juveniles (B) and Adults (C))

Juvenile spotted scat utilized Pak Phanang mangrove forest for habitat, shelter and food source. They often seek for particular microhabitat to spend their early lives. Small individuals of *Scatophagus argus*, total length 12-85 mm, most abundant size collected in mangrove forests often associated with prop roots and pneumatophores which offer shelter from predation (Shinnaka *et al*., 2007). This corresponded to findings in Trang Province (Tongnunui *et al*., 2002; Ikejima *et al*., 2003), Klong Ngao, Ranong Biosphere Reserve (Macintosh *et al*., 2002), shallow semi-enclosed estuarine Pattani Bay, Pattani Province (Hajisamae *et al*., 2006) and mangrove plantation and mudflat, Pak Phang Bay, Nakhon Si Thammarat Province (Paphavasit *et al*., 2004), Pagbilao mangrove forest, Philippines (Pinto, 1987), Australian mangrove areas (Morton, 1990), in Fisherman Island mangrove forest (Laegdsgaard and Johnson, 1995).

Adult spotted scat mostly distributed in the Pak Phanang Bay and coastal area. They often come into Pak Phanang mangrove forests as feeding ground. This was consistent with in other estuaries such as Tsengwen Estuary (Kuo and Shao, 1999), Fitzroy River (Morgan *et al*., 2002) and the Kakadu region, northern Australia (Allen *et al*., 2002). Few adults distributed in mangrove forests due to shallow and turbid water. Turbidity limits fish vision, which can interfere with social behavior, foraging (Gregory and Northcote, 1993; Vogel and Beauchamp, 1999) and predator avoidance (Meager *et al*., 2006). This can have effects on visual sensitivities of predators and prey, and non-visual sensory abilities. Thus, they will migrate to mangrove areas for only spawning ground. From research of Ikejima *et al*. (2003), *Scatophagus argus* were found at intertidal muddy beach with mangroves, *Avicennia* sp. and mangrove creek 3 m deep at high tide mainly by *R. apiculata* corresponded with other areas namely the Selangor coast, Malaysia (Sasekumar *et al*., 1992), the mangrove of Grajagan, East Java (Martosewojo and Soedibjo, 1991), the mangrove estuaries of tropical Australia (Ley *et al*., 2002) and found near *Rhizophora* microhabitats in the Pagbilao mangroves, Philippines (Rönnbäck *et al*., 1999). Therefore, Adult fish often perform feeding migrations into mangrove habitats where they preferably or exclusively forage. The feeding migrations can be based on a tidal, a diurnal or on a seasonal basis. In spawning season, adults migrate to spawn in mangrove areas (Janekarn, 1993; Tongnunui *et al*., 2002).

### 2.2 Factors determining the distribution and abundance in spotted scat

Salinity, temperature, dissolved oxygen, pH and transparency showed negative correlation with density of adult fish as in Table 2.8. Zooplankton in size >103 μm showed positive correlation with juveniles. However, the adult density showed inversed correlation with the zooplankton in size >103 μm.

Adult spotted scat were found in high density and distributed in estuarine waterway. Few adult spotted scat distributed in mangrove forests due to diel environmental parameters change such as salinity, dissolved oxygen, pH and transparency or turbidity that change from tidal influences and shallow water area. This situation affected the adult spotted scat to escape to the other areas. Generally, temperature was the major controlling factor through its effect on the rate of fish metabolic processes. Mortality, caused directly by temperature extremes in the shallow estuarine areas, is rared because fish gradually adjust their distribution in response to temperature change (Gibson, 1994). However only under extreme conditions of high temperature associated with other abiotic factors such as low oxygen concentrations and high salinities fish mortality can be observed (Pomfret *et al.*, 1991).

Low oxygen concentration was one of the important lethal factor in environments prone to hypoxia. The metabolic costs of osmo- and ionoregulation cause the salinity factor as one of the direct factor for fish that experienced the changes in salinity (Wootton, 1999). Iono- and osmoregulation are required for the distribution in the estuarine waterways (Jobling, 1995) Therefore, adult spotted scat mostly inhabit in estuarine waterway and moved into mangrove forest for feeding in short period following the tides and during spawning period. Turbid waters often correlated with juvenile marine fish as in KwaZulu-Natal estuaries and in the laboratory tests (Cyrus and Blaber, 1987 a,b). In their studies, 80% of the fish species were turbid water taxa, whereas only 20% could be classed as truly clear water species.

Blaber (1997) reported that postlaval fish in the marine environment, by following an increasing turbidity gradient, could ultimately reach shallow estuarine areas. It was suggested that the protective isolation created by turbidity, coupled with other factors, are advantageous to the survival and growth of juveniles in estuarine. Thus, juvenile spotted scat often distributed in the mangrove forest and gained benefit from low transparency or turbid water by reducing predation pressure. This also provides suitable food sources associated with shallow waters.

Food availability, in term of zooplankton density, was also the important factor affecting the fish abundance. Zooplankton served as food for juvenile spotted scat indicating an overall net benefit in selecting the mangrove habitat. The majority of zooplankton in size >103 μm was holoplanktonic component namely copepod nauplii, calanoid copepod, cyclopoid copepod and rotifer as main food sources of juvenile spotted scat. However the highest density of adult spotted scat correlated with zooplankton in size >330 µm community recorded the highest density varied from $9.50 \times 10^2$ to $3.73 \times 10^5$ individuals/100 $m^3$ in low salinity period. The dominant groups of zooplankton in size >330 µm were holoplanktonic and meroplanktonic component such as calanoid copepod, brachyuran larvae, shrimp larvae and lucifer as food items of adult spotted scat. Large size zooplankton were more suitable than small size for adult mouth gape (Wootton, 1999).

Table 2.8 Pearson Correlation test between environmental parameters and food sources with density of spotted scat during high and low salinity periods

| **Environmental parameters and food sources** | **Density of Spotted scat** | | |
|---|---|---|---|
| | **Fish larvae** | **Juveniles** | **Adults** |
| Salinity (psu) | 0.131 | 0.284 | -0.575* |
| Temperature ($^{o}$C) | 0.054 | -0.058 | -0.722* |
| Dissolved Oxygen (mg./l) | 0.213 | 0.191 | -0.531* |
| pH | 0.412 | 0.582* | -0.696* |
| Transparency (m.) | -0.260 | -0.628* | -0.729* |
| Water depth (m.) | -0.126 | 0.330 | -0.029 |
| Microphytoplankton (cell/l) | -0.001 | 0.199 | 0.607 |
| Zooplankton in size >103 µm (inds./100m$^{3}$) | 0.211 | 0.713* | -0.702* |
| Zooplankton in size >330 µm (inds./100m$^{3}$) | 0.310 | 0.325 | 0.121 |
| Organic detritus as total forest biomass (g/m$^{2}$) | 0.074 | -0.165 | -0.595 |

Remark: * Correlation is significant at 0.05 level (1-tailed)

### 2.3 Spotted scat fisheries in Pak Phanang Estuary

From the fishery survey by using questionnaires among the local fishermen (n=39) in Pak Phanang Estuary (Table 2.9), small-scale fishermen still earn their livings from Pak Phanang Bay and the surrounding mangrove forests. Their main fishing grounds were in the vicinity of Laem Talumpuk, Pak Phaya, Pak Phanang, Pak Poon and Pak Nakhon. The fishing grounds mainly in the estuary or the mangrove area at water depth from 1-3 m. The fishing intensity and effort revealed that they worked approximately 6 days a week and usually fished 9 hours in day time. Family members were their labour forces often 2-3 persons. They usually employed 1 hired fishing labour as their assistant. The average wage for fishing was 20 baht/person. Most boats were larger than 8 m with engine of smaller than 100 horsepower. Several types of fishing gears were used in the bay ranging from stationary gears in the shallow areas to small boat using push-nets, gill nets, or trawls. Most common gear was gill net of 63.41% with the average mesh size of 3.5 cm. Push net and fishing stakes are next in term of common fishing gears used. The dominant fish species in catch were found in 16 families namely Mugilidae, Scatophagidae, Sciaenidae, Ariidae, Plotosidae, Gobiidae, Bagridae, Ambassidae, Scrombidae, Polynemidae, Sillaginidae, Siganidae, Engraulidae, Clupeidae, Lutjanidae and Serranidae, repectively. These fish corresponded to the result in the mangrove fish communities from this study.

Table 2.9 Fishery status in Pak Phanang Estuary during May 2004-October 2005 from the fishery survey

| **Fishery status** | **Percentage of respondents** |
|---|---|
| **1. Fishing ground** | |
| 1.1 Laem Talumpuk | 19.05 |
| 1.2 Pak Phaya | 19.05 |
| 1.3 Pak Phanang | 19.05 |
| 1.4 Pak Poon | 14.29 |
| 1.5 Pak Nakhon | 9.52 |
| 1.6 Bang Kwai | 2.38 |
| 1.7 Bang Jark | 2.38 |
| 1.8 Ban Bia | 2.38 |
| 1.9 Bang Luk-Ban Pia | 2.38 |
| 1.10 Bang Gong Kong | 2.38 |
| 1.11 Bang Yai | 2.38 |
| 1.12 Ban Pak Khwang | 2.38 |
| 1.13 Aie hor | 2.38 |
| **2. Fishing intensity and effort** | |
| 2.1 Number of fishing day/week | |
| 2.1.4 6 days | 40.00 |
| 2.1.3 5 days | 22.22 |
| 2.1.5 7 days | 17.78 |
| 2.1.2 4 days | 8.89 |
| 2.1.6 not sure | 6.67 |
| 2.1.1 3 days | 4.44 |
| 2.2 Number of hour | |
| 2.2.5 9 hours | 22.50 |
| 2.2.8 12 hours | 17.50 |
| 2.2.4 8 hours | 12.50 |
| 2.2.1 5 hours | 12.50 |
| 2.2.10 low tide-high tide duration | 12.50 |
| 2.2.6 10 hours | 10.00 |
| 2.2.7 11 hours | 7.50 |
| 2.2.3 7 hours | 2.50 |
| 2.2.2 6 hours | 2.50 |

Table 2.9 (Continued)

| **Fishery status** | **Percentage of respondents** |
|---|---|
| 2.3 Time of the day during fishing | |
| 2.3.1 Day catch | 89.74 |
| 2.3.2 Night catch | 10.26 |
| 2.4 Family members in fishing (person) | |
| 2.4.2 3 persons | 50.00 |
| 2.4.1 2 persons | 50.00 |
| 2.5 Fishing labour hired (person) | |
| 2.5.2 1 person | 56.41 |
| 2.5.1 Not hired | 33.33 |
| 2.5.3 2 persons | 10.26 |
| 2.6 Wage for hired labour | |
| 2.6.3 Percentage 20 baht/person | 38.89 |
| 2.6.2 Percentage 16 baht/person | 27.78 |
| 2.6.5 Percentage 30 baht/person | 27.78 |
| 2.6.1 Percentage 15 baht/person | 16.67 |
| 2.6.4 Percentage 25 baht/person | 16.67 |
| **3. Size of boat (m.) and engine (horsepower)** | |
| 3.1 Boat (m.) | |
| 3.1.2 Boat larger than 8 m. | 69.44 |
| 3.1.1 Boat smaller than 8 m. | 30.56 |
| 3.2 Engine (horsepower) | |
| 3.2.1 Engine smaller than 100 horsepower | 90.90 |
| 3.2.2 Engine larger than 100 horsepower | 9.10 |
| **4. Type of fishing gear** | |
| 4.1 fishing gear | |
| 4.1.1 Gill net | 63.41 |
| 4.1.2 Push net | 17.07 |
| 4.1.3 Fishing stakes | 14.63 |
| 4.1.4 Shrimp gill net | 2.44 |
| 4.1.5 Stow net | 2.44 |

Table 2.9 (Continued)

| Fishery status | Percentage of respondents |
|---|---|
| 4.2 Gill net mesh size (cm.) | |
| 4.2.2 Mesh size 3.5 cm. | 74.29 |
| 4.2.3 Larger than 3.5 cm. | 17.14 |
| 4.2.1 Smaller than 3.5 cm. | 8.57 |
| **5. Dominant fish species in catch** | |
| 5.1 Mugilidae | 30.77 |
| 5.2 Scatophagidae | 21.15 |
| 5.3 Sciaenidae | 9.62 |
| 5.4 Ariidae | 8.65 |
| 5.5 Plotosidae | 6.73 |
| 5.6 Gobiidae | 3.85 |
| 5.7 Bagridae | 3.85 |
| 5.8 Ambassidae | 2.89 |
| 5.9 Scrombidae | 2.89 |
| 5.10 Polynemidae | 1.92 |
| 5.11 Sillaginidae | 1.92 |
| 5.12 Siganidae | 1.92 |
| 5.13 Engraulidae | 0.96 |
| 5.14 Clupeidae | 0.96 |
| 5.15 Lutjanidae | 0.96 |
| 5.16 Serranidae | 0.96 |

Data on spotted scat fisheries in Pak Phanang Bay during May 2004-October 2005 from the fishery survey (Table 2.10, Figure 2.16) showed spotted scat distributed in Pak Phanang Bay and mangrove forest. The average size catch of spotted scat were 6-10 cm. Total catch on the average was 11-30 individuals/day with total weight of 1-10 kg. Smallest size in catch were 1 cm weighting. The highest density recorded in July-August. The normal sex ratio of 1:1 was found from September to October. The first sexual maturity size in female was 5-6 cm. The fishermen differentiated between the sexes by cut open the stomach showing ovary. Spawning season can occur throughout the year. High peaks of mature oocytes recorded during July-August. Females often migrate to spawn in mangrove forests. Schools of fish larvae were easily captured in mangrove forests and mud flats. The highest abundance of fish larvae collected from July to

October. Results from fishery survey confirmed the distribution pattern of spotted scat in Pak Phanang Estuary from this study (Figure 2.12-2.15). Spotted scat utilized mangrove forest as nursery ground in larval stage in size 1-2 cm. Schools of fish larvae were easily found in mangrove forests. Moreover, juvenile seek shelter from predators in mangrove forests. Adult spotted scat mostly distributed in the Pak Phanang Bay and coastal area. They often come into Pak Phanang mangrove forests as feeding ground and spawning areas during spawning season. Moreover, feeding ecology in spotted scat from the fishery survey also confirm this study that the fish was mostly omnivore. Plant/algae, crustacean larvae and detritus were prey items.

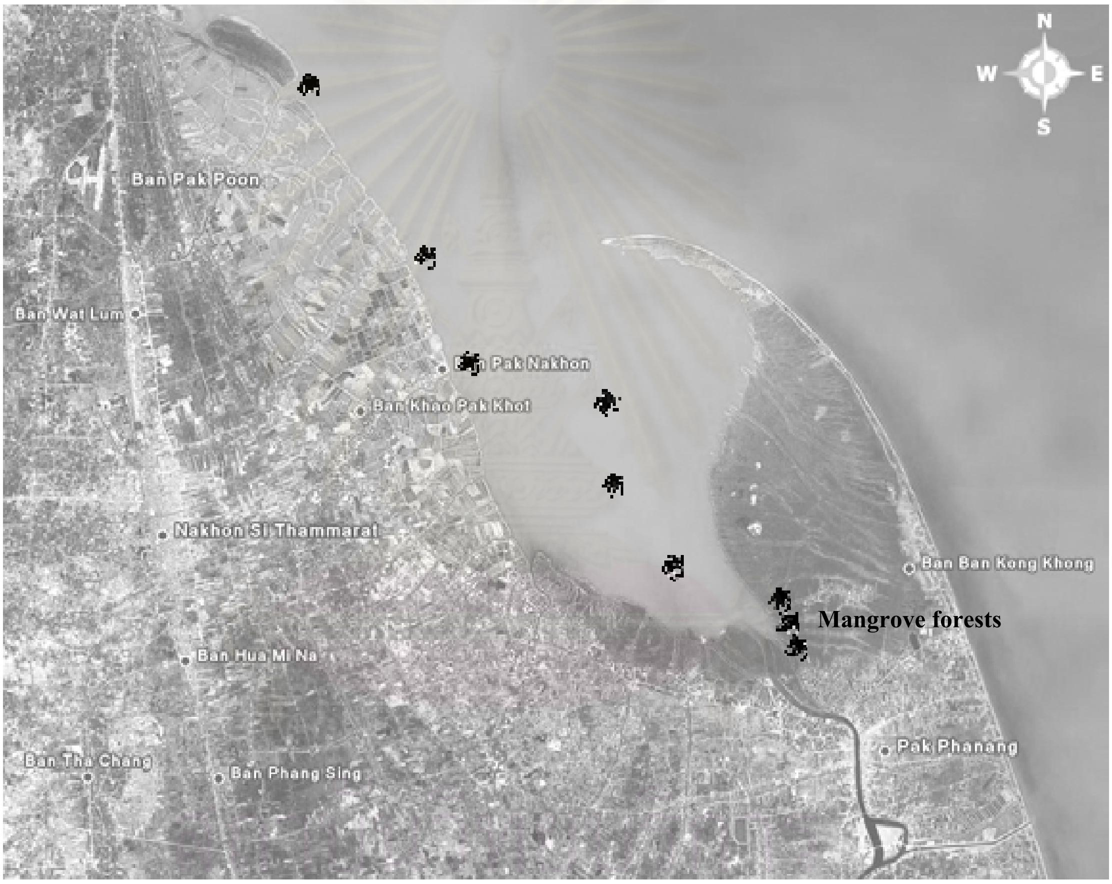



Figure 2.16 Spotted scat fishing ground in Pak Phanang Estuary, Nakhon Si Thammarat Province

Table 2.10 Spotted scat fisheries in Pak Phanang Bay during May 2004-October 2005 from the fishery survey

| Spotted scat fishery status | Percentage of respondents |
|---|---|
| **1. Common habitat** | |
| 1.1 Pak Phanang Bay | 43.48 |
| 1.2 Mangrove forest | 28.26 |
| 1.3 Mud flat | 21.74 |
| 1.4 Coastal area | 6.52 |
| **2. Total catch/day** | |
| 2.1 Size of fish (cm.) | |
| 2.1.2 6-10 cm. | 52.73 |
| 2.1.1 1-5 cm. | 30.91 |
| 2.1.4 16-20 cm. | 10.91 |
| 2.1.3 11-15 cm. | 5.46 |
| 2.2 Total catch (individuals)/day | |
| 2.2.2 11-30 individuals | 28.21 |
| 2.2.4 51-100 individuals | 25.64 |
| 2.2.1 1-10 individuals | 17.95 |
| 2.2.3 31-50 individuals | 17.95 |
| 2.2.5 101-300 individuals | 10.27 |
| 2.3 Total weight (kg.) | |
| 2.3.1 1-10 kg. | 72.42 |
| 2.3.2 11-30 kg. | 17.24 |
| 2.3.3 More than 31 kg. | 6.90 |
| 2.4 Smallest size in catch | |
| 2.4.1 Length (cm.) | |
| 1. 1 cm. | 34.09 |
| 3. 2 cm. | 27.27 |
| 5. 4 cm. | 20.46 |
| 4. 3 cm. | 13.64 |
| 2. 1.5 cm. | 2.27 |
| 6. 5 cm. | 2.27 |

Table 2.10 (Continued)

| **Spotted scat fishery status** | **Percentage of respondents** |
|---|---|
| 2.4.2 Weight (g.) | |
| 2. 1 g. | 68.00 |
| 3. 2 g. | 20.00 |
| 1. 0.5 g. | 12.00 |
| **3. Behavior** | |
| 3.1 School | 100.00 |
| **4. Time of the year when highest density recorded** | |
| 4.4 July-August | 56.25 |
| 4.5 September-October | 29.17 |
| 4.3 June-July | 8.33 |
| 4.2 March-April | 2.08 |
| 4.6 November-December | 2.08 |
| 4.1 January-February | 2.08 |
| **5. Reproductive biology** | |
| 5.1 Sex Ratio | |
| 5.1.1 Female>Male (July-August ) | 5.00 |
| 5.1.2 Male>Female (July-August ) | 15.00 |
| 5.1.3 Male=Female | |
| 2. July-August | 50.00 |
| 3. September -October | 20.00 |
| 1. March-April | 5.00 |
| 4. November-December | 5.00 |
| 5.2 First maturation size in female (cm.) | |
| 5.2.1 5-6 cm. | 58.70 |
| 5.2.2 6.1-7 | 32.61 |
| 5.2.3 7.1-8 | 6.52 |
| 5.2.4 Larger than 8 | 2.17 |

Table 2.10 (Continued)

| **Spotted scat fishery status** | **Percentage of respondents** |
|---|---|
| 5.3 Spawning season | |
| 5.3.1 July-August | 23.21 |
| 5.3.4 October-November | 21.43 |
| 5.3.3 September-October | 14.29 |
| 5.3.5 November-December | 14.29 |
| 5.3.6 December-January | 14.29 |
| 5.3.2 August-September | 10.71 |
| 5.3.7 All year | 1.79 |
| 5.4 Spawning area | |
| 5.4.1 Mangrove forest | 58.46 |
| 5.4.2 Coastal area | 24.62 |
| 5.4.3 Pak Phanang Bay | 10.77 |
| 5.4.4 Pak Phanang River | 4.62 |
| 5.4.5 Mud flat | 1.54 |
| **6. Feeding Ecology** | |
| 6.1 Larvae (1-2 cm.) | |
| 6.1.1 Omnivore (plant/algae, crustacean larvae, detritus) | 34.78 |
| 6.1.2 Herbivore (plant/algae, thallophytic plant) | 30.43 |
| 6.1.3 Zooplankton feeder (cirripedia, mysid, bivalve larvae, shrimp larvae) | 21.74 |
| 6.1.4 Detritivore (Detritus) | 13.04 |
| 6.2 Juvenile and adult (larger than 3 cm.) | |
| 6.2.1 Omnivore (plant/algae, crustacean larvae, detritus) | 50.00 |
| 6.2.2 Herbivore (plant/algae, thallophytic plant) | 20.83 |
| 6.2.3 Zooplankton feeder (cirripedia, mysid, bivalve larvae, shrimp larvae) | 20.83 |
| 6.2.4 Detritivore (Detritus) | 8.33 |

**Opinions on fishery status in the Pak Phanang Estuary**

The local fishermen as revealed from the questionnaires noticed the changes in the fishery production in term of sharp decline in density and size of spotted scat and other commercial fish. When asked to compare their fishery production before and after 1999 which marked the operation of the irrigation regulators in Pak Phanang Estuary, the fishery production before 1999 was high of 5-30 kg/day of spotted scat size 5-8 cm and 10-15 kg/day in size 3-5 cm at daytime. The mangrove forests were diversed. Two district seasons controlling the fishery production were observed: wet season from October to January and dry season from March to August. After the year 1999, they noticed the decline in total catch. Dominant fish species clearly showed the decline in total density and size. The catch was reduced two-folds recorded 5-15 kg/day of spotted scat size 5-8 cm and 3 kg/day in size 3-5 cm. The local fishermen expressed their opinions on the decline in fishery production that the fishermen used the smaller mesh size for gill net and other fishing gear and the degraded mangrove forests. They also felt that the operation of the dam has disrupted the circulation and water exchange processes. Water quality is also affected in term of salinity changes. Penetration of seawater on daily tides and the reduction of freshwater input were affected by the dam. Overfishing, degraded mangrove forests and pollutions from human activities in term of shrimp farming and urbanization contributed to the declined fishery production in this area.

## E. Conclusion

### 1. State of Mangrove Dependency in Fish Communities Related to Food Sources

The mangrove plantations in Pak Phanang Estuary supported the availability of habitat and food sources. Fish of the total 50 species recorded in 27 families, 5 families seek mangrove forest as nursery area namely Clupeidae, Atherinidae, Syngnathidae, Blenniidae and Sphyraenidae. The true resident species were found in 9 families of Engraulidae, Ambassidae, Leiognathidae, Gerreidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae and Cynoglossidae. Partial residents entering into the forest as feeding ground were those fish in 13 families Megalopidae, Bagridae, Ariidae, Plotosidae, Mugilidae, Phallostethidae, Hemiramphidae, Aplocheilidae, Scorpaenidae, Sillaginidae, Sciaenidae, Callionymidae and Tetraodontidae.

Spotted scat, *Scatophagus argu*s, is one of the true resident species in the Pak Phanang mangrove forest. This study showed the high abundance of spotted scat larvae in Pak Phanang mangrove forest that showed the important of mangrove for nursery ground. The diversities of microhabitat from structure mangrove plant and food sources including microphytoplankton and zooplankton in mangrove forest were used for shelter and food sources. While juvenile spotted scat distributed in mangrove forest and utilized mangrove forest as habitat and feeding ground. They often seek for particular microhabitat to reside. Adult spotted scat were distributed in estuarine waterway. They often perform feeding migrations into mangrove habitats where they preferably or exclusively forage. They also migrate to spawning in mangrove areas during spawning season.

Food supply was the major factor inducing these fish to come into the mangrove proper and fringes. The result showed diversity of food sources for fish communities such as microphytoplankton. The most dominant and most frequent of microphytoplankton were diatoms and cyanobacteria. Zooplankton community was dominated by arthropod crustacean in particular copepods which contributed more than 60% of the total zooplankton density. Organic detritus in form of underground, pneumatophore and seedling biomass in the mangrove plantations was 443.06 $g/m^2$. Dense tree canopy in the mangrove plantations contributed to this high organic content. Although organic detritus in term of forest biomass increasing, low diversity of benthos recorded in the area. This was due to the hypoxia condition in the Pak Phanang Bay and in the mangrove forests. Hypoxia condition in the area resulted from human activities in term of shrimp farmings and urbanization. Conversion of mangrove forests to shrimp farms, not only lead to degraded mangroves, but also change the hydrology of the area and increase sedimentation from shrimp farm effluents. Moreover the sedimentation rate in the Pak Phanang Estuary was quite rapid thus the exchange rate between the estuary and coastal seas was affected. In addition, tidal cycles cloud not flood forest biomass that high litter falls covered the mangrove floor into estuary. In addition, the mangrove floor of Klong Bang Hua Koo and Kong Bang Luk was flooded only during spring tide. Although the mangrove reforestation has been carried out since 1982, but the mangrove plantations were not maintained according to the silviculture technique in order to promote production. Thinning and pruning have not been carried out. In the long term, even with high forest biomass as the mangrove plantation aged, but these hypoxia conditions are not suitable for benthos. The availability of habitats and food sources will soon be lost. Moreover, fish could not utilize the mangrove forests as food sources in hypoxia condition.

**2. Environmental Quality as the Main Factors Controlling Habitat Utilization**

Habitat utilization of fish community in mangrove forest was controlled by environmental parameters and mangrove forest characteristics. The important environmental parameters were dissolved oxygen and salinity changes. Oxygen depletion within the water column has the potential to restrict the distribution and movement of fish within estuaries. Periodic dissolved oxygen depletion can also occur during episodic river floods which, together with excessive soil loads, may cause mass mortalities of fish. Moreover, high water salinity in long period will effect to soil salinity is a major factor limiting growth and primary productivity in the mangrove forest and also affected to diversity and density of food sources in mangrove forest. Salinity is relevant to the distribution pattern. Food sources will induce fish into mangrove forest. During high salinity, Cyanophyceae were comprised approximately 60% of total microphytoplankton density, meanwhile diatom were dominant group in low salinity period. The occurrence of rotifers and brachyuran larvae collected in low salinity. The larvaceans found in abundance in the high salinity. Thus, the diversity and abundance of food source in the Pak Phanang mangrove forest have drawn in fish from the total of 27 families. Most estuarine fish are able to cope with salinity fluctuations, but their ability to do so vary from species to species and hence may influence their distribution. The increased abundance of fish species, which adapts well to low salinities, was probably linked to the large blooms of microphytoplankton and zooplankton in the wake of the floods, as well as the more favorable lower salinities. From the data on the fish assemblage in Pak Phanang Estuary reported, only 21 species belonging to 13 families were tolerated environmental changing such as low dissolved oxygen conditions and variable salinity regimes characteristic of mangrove ecosystems namely *Stolephorus insularis*, *Thryssa hamiltonii*, *Escualosa thoracata*, *Sardinella albella*, *Mystus gulio*, *Plotosus canius*, *Chelon permata*, *Neostethus lankesteri*, *Vespicula trachinoides*, *Sillago sihama*, *Dendrophysa* *russelli*, *Butis butis*, *Acentrogobius canius*, *Acentrogobius viridipunctatus*, *Parapocryptes serperaster*, *Pseudapocryptes lanceolatus*, *Stigmatogobius sadanundio*, *Taenioides cirratus*, *Scatophagus argus*, *Siganus canaliculatus* and *Siganus javus*. While families Clupeidae, Atherinidae, Syngnathidae, Blenniidae and Sphyraenidae spend their time mostly in mangrove forest for nursery and forage. Pelagic plankton feeding clupeid also dominant, some benthic feeding fish, Eleotridae and Gobiidae were also abundant.

Spotted scat utilized mangrove forest as nursery ground in larval stage. Schools of fish larvae were easily found in mangrove forests and mud flats. While, mangrove forests were habitat areas in juvenile stage for shelter predator and feeding ground for adult spotted scat. Juvenile spotted scat gained benefit from turbid water by reducing predation pressure and favoring the development of suitable food associated with shallow waters. As fish grow a shift in habitat from mangroves to estuarine was a response to change in environment parameter. They will migrate to mangrove areas for only spawning ground in spawning season. Those fish with immature oocytes, move inshore to spawning. Adult spotted scat were found high density and distributed in estuarine waterway in low salinity period. Few adult spotted scat distributed in mangrove forests due to shallow water. Corresponding to fishery survey, the adult fish often live offshore in deeper waters. Additionally, estuarine waterways provided less variation in temperature due to water depth supporting high density of adult spotted scat in this area. From fishery survey, during wet season in particular the month of October, most spotted scat were found outside the bay in the coastal area. The catches were low during this month.

The role of mangrove forest supported the availability of food source for spotted scat. Food availability in term of microphytoplankton abundance supported density of spotted scat larva. Zooplankton were the food items for juvenile spotted scat indicating an overall net benefit in selecting the mangrove habitat. The majority of zooplankton component were copepod nauplii, calanoid copepod, cyclopoid copepod and rotifer as main food source of juvenile spotted scat. The highest density of adult spotted scat also correlated with zooplankton community recorded in highest density in low salinity period. In addition organic detritus as forest biomass was additional food sources for spotted scat in every stages. Benthos were found as food items for adult spotted scat.

From the fishery survey by using questionnaires among the local fishermen in Pak Phanang Estuary, small-scale fishermen still earn their livings from Pak Phanang Bay and the surrounding mangrove forests. Their main fishing grounds were in the vicinity of Laem Talumpuk, Pak Phaya, Pak Phanang, Pak Poon and Pak Nakhon. The fishing grounds mainly in the estuary or the mangrove area at water depth from 1-3 m. Several types of fishing gears were used in the bay ranging from stationary gears in the shallow areas to small boat using push-nets, gill nets, or trawls. Most common gear was gill net of 63.41% with the average mesh size of 3.5 cm. Push net and fishing stakes are next in term of common fishing gears used. The dominant fish species in catch were found in 16 families namely Mugilidae, Scatophagidae, Sciaenidae, Ariidae, Plotosidae, Gobiidae, Bagridae, Ambassidae, Scrombidae, Polynemidae, Sillaginidae, Siganidae, Engraulidae, Clupeidae, Lutjanidae and Serranidae, repectively. These fish corresponded to the result in the mangrove fish communities from this study.

Data on spotted scat fisheries in Pak Phanang Bay during May 2004-October 2005 from the fishery survey confirmed the distribution pattern of spotted scat in Pak Phanang Estuary from this study. Spotted scat utilized mangrove forest as nursery ground in larval stage in size 1-2 cm. Schools of fish larvae were easily found in mangrove forests. The highest abundance of fish larvae collected from July to October. Moreover, juvenile seek shelter from predators in mangrove forests. Adult spotted scat mostly distributed in the Pak Phanang Bay and coastal area. They often come into Pak Phanang mangrove forests as feeding ground and spawning areas during spawning season.

The local fishermen as revealed from the questionnaires noticed the changes in the fishery production in term of sharp decline in density and size of spotted scat and other commercial fish. The local fishermen expressed their opinions on the decline in fishery production that the fishermen used the smaller mesh size for gill net and other fishing gear and the degraded mangrove forests. They also felt that the operation of the dam has disrupted the circulation and water exchange processes. Water quality is also affected in term of salinity changes. Penetration of seawater on daily tides and the reduction of freshwater input were affected by the dam. Overfishing, degraded mangrove forests and pollutions from human activities in term of shrimp farming and urbanization contributed to the declined fishery production in this area.

# CHAPTER III

# FEEDING ECOLOGY IN SPOTTED SCAT, *Scatophagus argus*

## A. Introduction

Spotted scat, *Scatophagus argus*, distributed along the coastline, mud flats, mangrove forest, estuarine area and sometimes carried up the river by tides in Pak Phanang Estuary, Nakhon Si Thammarat Province. Spotted scat utilized the mangrove area for nursery and feeding ground. Feeding ecology of spotted scat is also important in determining the roles of mangrove forests as food sources for these fish. There is often a correlation between morphological traits and trophic role because morphology determines how a fish can feed. Body shape, mouth morphology, teeth, gill rakers and the structure of digestive system can all be related to diet. Prey selection in fish depends on the visual perception, mechanical ability of fish to manipulate the prey successfully. Selection may depend also on the profitability of the prey (Wootton, 1999). Selection in most fish follows the optimal foraging theory assumes that food is chosen to maximize the profitability to the forager in relation to feeding structure morphology. Feeding strategies in different stages of spotted scat in relation to feeding structure morphology and diverse food sources, development of digestive system as well as the feeding preference will be investigated in details. These developments allow fish to feed on more diverse food sources leading to niche shift in different stages of spotted scat.

Feeding adaptation in fish allows them to exploit almost all available sources of food. A rich variety of foods exist in mangroves and estuaries. However, they may be large fluctuations in the type and numbers of prey available. Many fish are flexible in their choice of foods, responding to changes in the availability or profitability of potential prey. Such flexibility confers important advantage in terms of both survival and mobility in estuaries. Moreover, the detailed study on the feeding behavior and preferences of this spotted scat would help to determine whether this fish was "Specialist" dependent on particular food sources, concentrate their energies on a restricted type of food and rarely broaden their diet. "Generalist" feeds on various food sources and not feeding selectively on a prey item by feeding on abundant prey or being trophic adaptability "Opportunistic feeder" advantages more than specialists and generalist of, or feeds on, a source of food outside its usual diet. There was the lack of seasonal, tidal and temporal variations in feeding intensityFrom these results, the importance of mangrove forests as food sources and the roles of spotted scat in the mangrove food webs are able to be concluded.

## B. Literature Review

### 1. Morphological Adaptations for Feeding in Fish

Fish occupy every possible trophic role from herbivorous species to secondary and tertiary carnivores. Some species form part of detrital food webs. There is often a correlation between morphological traits and trophic role because morphology determines how a fish can feed.

1.1 Herbivorous fish: position and size of mouth different follow feeding types and feeding area namely subterminal mouth which often eat at bottom area. The species that are essentially benthic in their feeding habits usually have inferior mouths such as family Mugilidae which has major food is diatoms and blue green algae (Vitheesawat, 1999) villiform teeth, many and long gill rakers small stomach content and the intestinal length to body length was 8.6-14.4 (Figure 3.1).

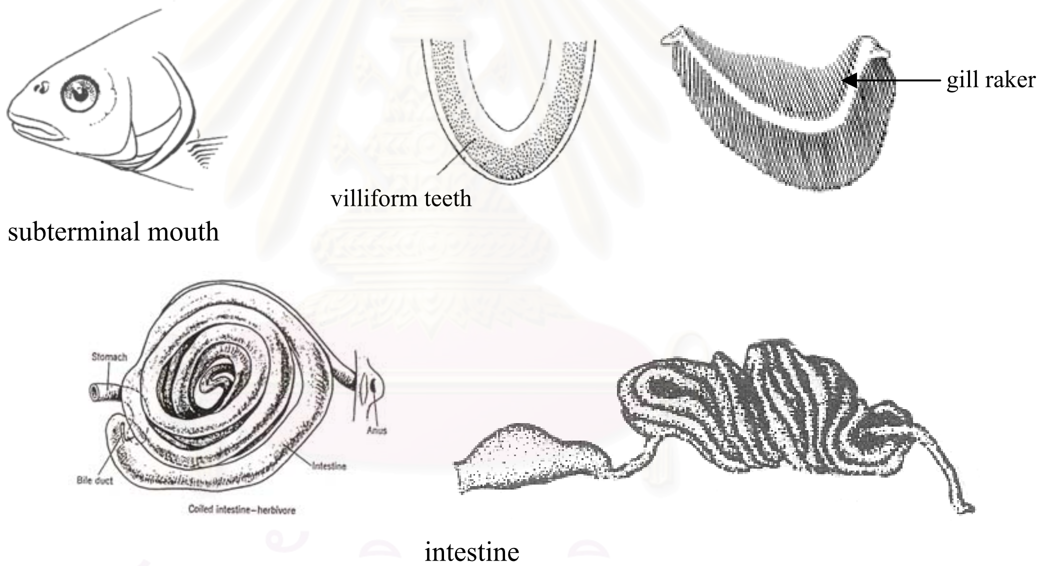



Figure 3.1 Feeding structure morphology in herbivorous fish (Lagler *et al*., 1962; Norman, 1975)

1.2 Plankton feeders: most fish feed at surface and middle water column also classified mouth position into 3 types namely superior mouth, terminal mouth and beak-like mouth. The most common position is terminal, which allows the fish to feed both at the surface and by stirring up the substrate. The more sedentary or passive hunters have superior mouths. Fish feed on phytoplankton or zooplankton, along with those that have tube-shaped mouths, have no teeth. They have long rakers that are thinner and more efficient at capturing microscopic particles. From studied of Plounevez and Champalbert (2000) studied the feeding type in *Engraulis encrasicolus* at the Gulf of Lions was strictly zooplanktivorous with copepod and crustacean larvae dominating in stomach content. Anchovy selected on large prey and filter-feeding mechanism on small prey. They have villiform teeth and long intestine with many pyrolic caeca (Figure 3.2).

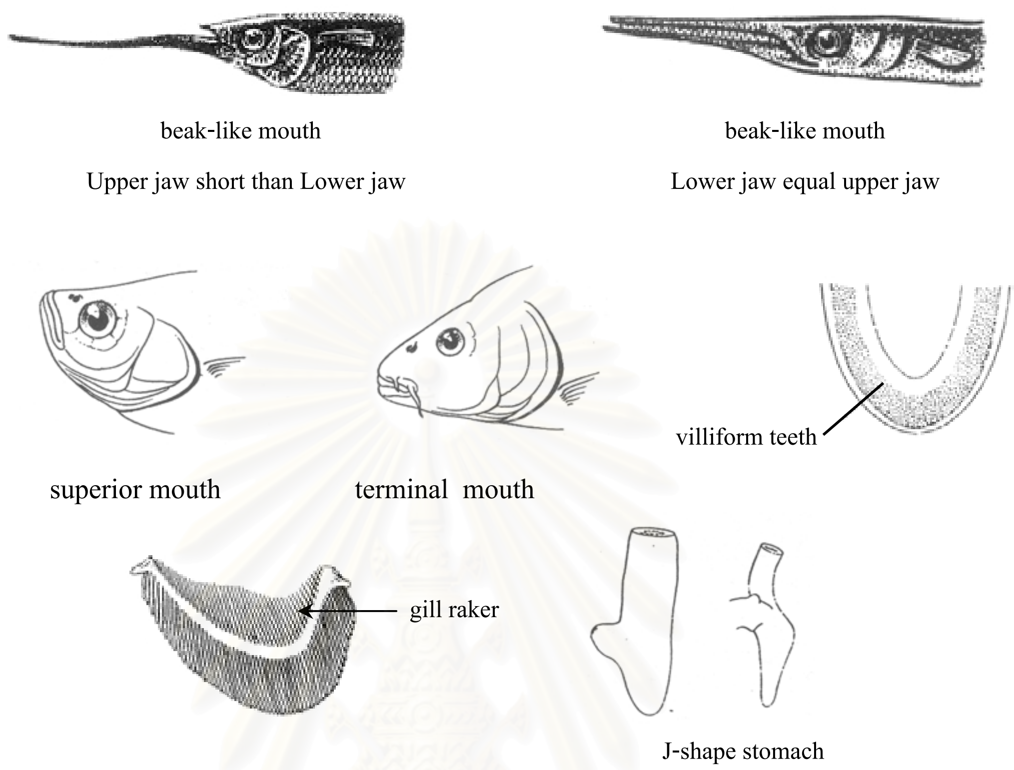
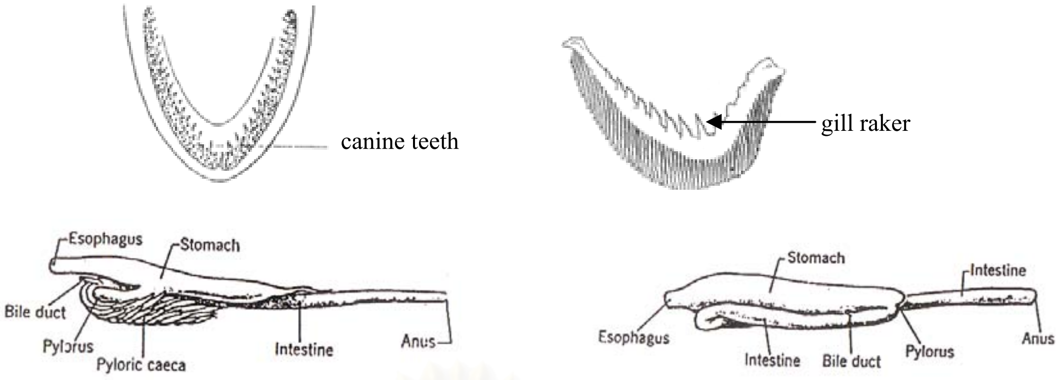



Figure 3.2 Feeding structure morphology in plankton feeders (Lagler *et al*., 1962; Norman, 1975)

1.3 Carnivorous fish: this group usually feed on marine benthic invertebrate and fish larvae such as Sillaginidae, Leiognathidae and Gerreidae (Vitheesawat, 1999) and Bothidae (Schafer *et al.*, 2002). Fish with large mouth gape such as Carangidae, Sphyraenidae, Ariidae and Plotosidae also belong to the same category. Predatory fish, feeding on nekton and macrobenthos, have mandibular dentition made up of numerous small but sharp teeth, canine in shape, which form an insuperable barrier for small prey. The more active predators have strong jaws and sharp teeth. Predatory species have fewer gill rakers, which are smaller and further apart. The number and size of these gill rakers correlates with the size of their prey. Fish have large stomach. The Y-shaped stomach or cecal is typical of carnivorous fish. The intestinal length to body length was less than 1.12. Additionally, fish present a greater number of villi and pyloric caeca, which amplify manifold and compensate for a relatively short intestine (Buddington *et al*., 1997). They used a variety of different strategies to capture their prey and can be classified in different groups based on the hunting techniques they employ and have good sensory organ (Figure 3.3).




straight digestive tract with pyloric caeca straight digestive tract without pyloric caeca

Figure 3.3 Feeding structure morphology in carnivorous fish (Lagler *et al*., 1962; Norman, 1975)

1.4 Omnivorous fish: this group can eat plant and animal or alternate depend upon food items position. Size of mouth has different excessively and other fish have protractile mouth such as Leiognathidae and Gerreidae. This feat is related to the fish's ability to be able to manipulate prey of various sizes within the mouth, reducing the chances that the prey will escape and essentially increasing sucking efficiency. Fish have teeth and there is a wide variety of shapes, mainly in accordance with diet. These teeth can be classified according to the bones on which they are situated: premaxillary and maxillary on the upper jaw; mandibulars associated with the dental bone of the lower jaw; the vomerine, palatine, ectopterygoid and parasphenoidal teeth in the palate. They have fewer gill rakers, which are smaller and further apart; the number and size correlates with the size of their prey. Number of gill rakers varies between herbivorous fish and carnivorous fish. Some species has the muscular gizzard where the grinding of food take place. The intestinal length to body length was 1.6-3.3. Vitheesawat (1999) found fish in this group namely Scatophagidae and Hemiramphidae (Figure 3.4)

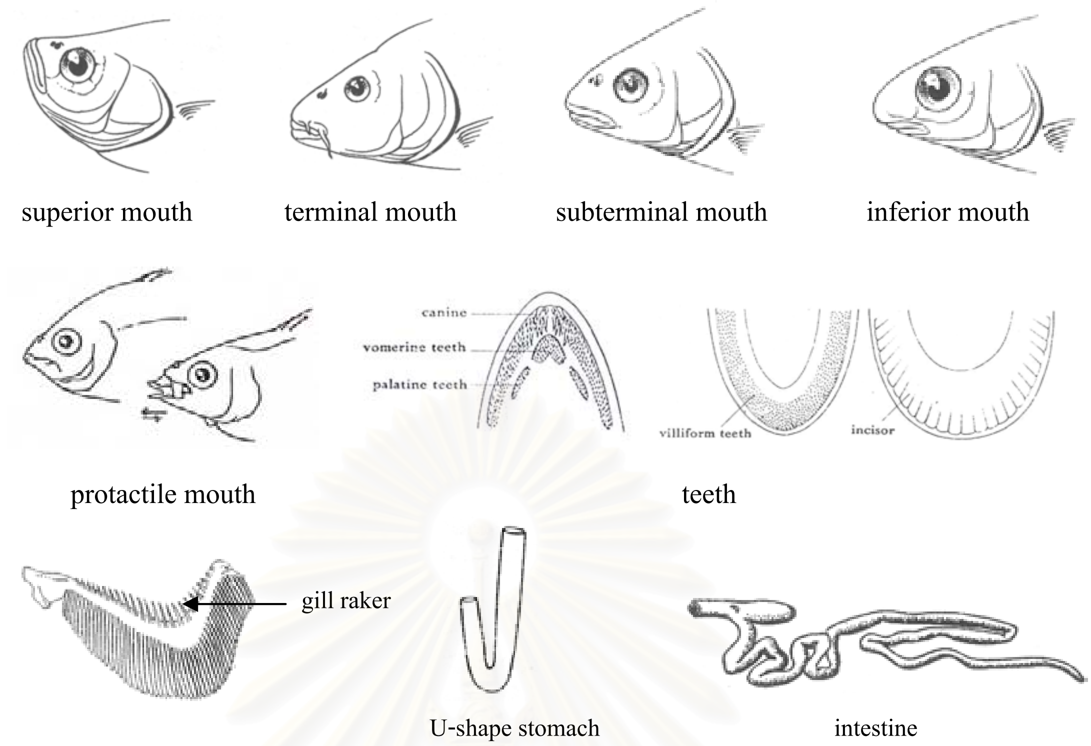



Figure 3.4 Feeding structure morphology in omnivorous fish (Lagler *et al*., 1962; Norman, 1975)

1.5 Detritivorous fish: this group usually feed detritus and sediment in bottom, therefore inferior mouth. Almeida (2003) found the feeding activity of the *Liza ramada* has organic matter ingested which comes from a different origin than planktonic or benthic microalgae. The *L. ramada* population showed a positive selection for sediment particles between 55 and 250 μm in diameter and found diatoms in food items (Figure 3.5).

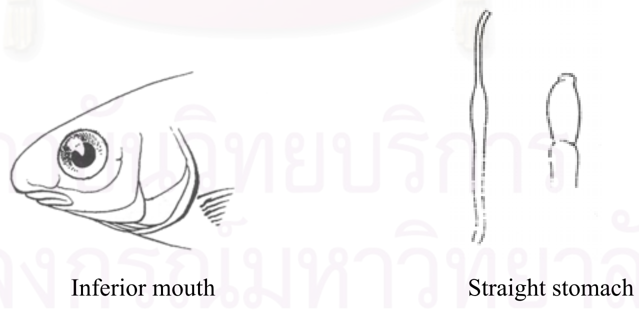



Figure 3.5 Feeding structure morphology in detritivorous fish (Lagler *et al*., 1962; Norman, 1975)

### 2. Prey Selection Based on Optimal Foraging Theory

The presence of a food item in a diet depends on its availability, its detection by the fish and its selection as food. Prey selection depends on visual perception, mechanical ability of the fish to manipulate the prey successfully; selection may depend also on the profitability of the prey. Optimal foraging theory has been used to predict the diet composition of some species on the basis of prey profitability.

#### 2.1 Size selection

Size selection in fish as optimal prey size of mouth size is the strategy to maximizes food consumed per unit capture plus handing time. The majority of predatory fish eat their prey whole which leads to a prey size range encompassing small prey at the lower limits of visual detection or which are physically too small to be retained by gill rakers to those at the upper limits, which are too large for the jaw apparatus. An increase in predator size will widen the range of prey that can be included in the diet. Fish’s body size increases allometric growth results in the mouth getting larger hence an ever increasing range of prey sizes can be consumed. For any given predator size the amount of energy contained in a prey and the prey handling time increases with prey size. Therefore, the most profitable prey will be found somewhere between A and B (Gill, 2003) (Figure 3.6).

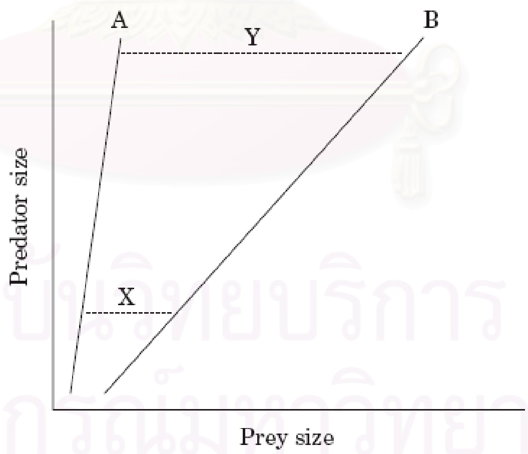



Figure 3.6 The prey size range available to a predator that eats its prey whole. The solid lines represent the minimum prey size (A) and maximum prey size that can be eaten (B). Small predators have a restricted range of prey sizes available to them (X) whereas large predators have a much wider range (Y) (Gill, 2003).

Houde (1997) studied size selective feeding by three cohorts of fish larvae preying upon three size classes of a copepod. Sizes of copepods eaten by the three hypothetical cohorts of larvae overlap broadly, showing preferences distributed over a relatively wide size spectrum. Small preys continue to be included in the diet, even by the largest larval cohort. Abundances of larvae at each size are those predicted for a cohort of "typical" marine fish larvae. The dashed lines represent the hypothesized declines in abundances of larvae and copepods. Frequency distributions of larval sizes for the three larval cohorts are indicated in the top panel while the "breadths" of copepod sizes included in their diets are indicated in the bottom panel. Arrows indicated the mean size of prey eaten by a larval of mean size in each cohort (Figure 3.7).

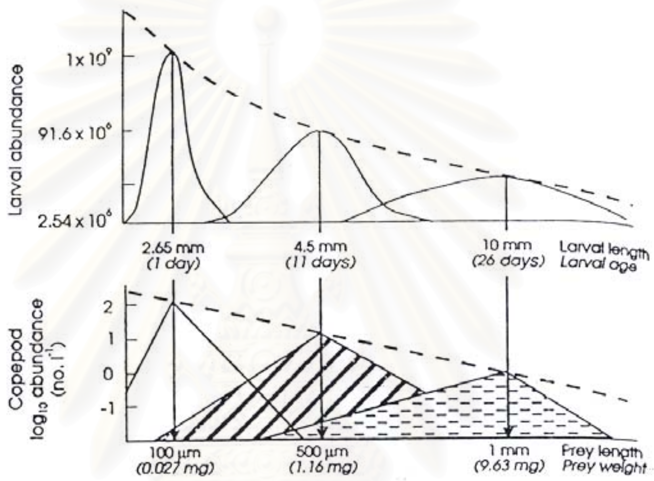



Figure 3.7 Strategy of preference feeding of fish larvae

Lukoschek and McCormick (2001) studied food types and food size of *Parupeneus barbernius* in various size classes. *Parupeneus barbernius* forages on benthic invertebrates using a wide range of foraging modes. Polychaetes were the most important prey item for all size classes, but fish less than 120 mm total length consumed more small ostracods and nematodes than did larger fish. Fish greater than 120 mm total length consumed mostly bivalves, and fish over 240 mm total length consumed mostly bivalves and crabs. A morphological examination of the feeding apparatus suggested that the size of important prey items consumed was determined by gape height and jaw width. Prey available to different size classes of fish was determined by combining information on microhabitat use, foraging behaviors, and prey volumes in the substratum.

**2.2 Food density**

Food density also plays a role in choosing among prey types. When food is scarce, it is less profitable to spend the additional time necessary to locate only valuable prey items. When profitable preys are common more food will be obtained by passing over less valuable items and restricting the diet to a reduced set of valuable prey types. Holling's Functional Response showed the correlation between prey captured and prey density that reflected the feeding types (Levinton, 1982) in Figure 3.8. The availability of the prey to predators depends not only on its population density, but also on its activity, exposure and defence mechanisms (Vinyard, 1980). Defensive structure and behavior make a potential prey less profitable to the predator because the handling time increases. In some cases, prey selection depends on experience and formation of search images.

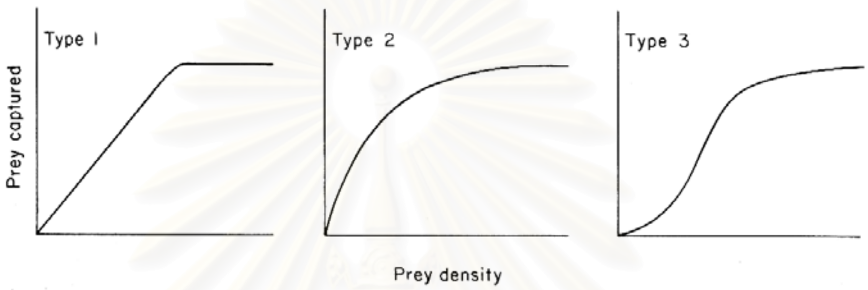



Figure 3.8 Feeding type according to Holling's Functional Response (Levinton, 1982)

1. Consumption increases linearly with resource density until an upper density, beyond which consumption does not increase. Fish with Type 1 functional responses are consumers that require little or no time to process their food; for example, some filter-feeding fish feeding on small preys.

2. There is an increase of the resource taken with increasing resource density but with a logarithmic deceleration to a plateau. Exploit by random encounter can take progressively smaller increments of resource with increasing resource density. At low food densities, feeding rate appears limited by how long it takes fish to find food. At intermediate food densities, the animal's feeding rate is partly limited by the time spent searching for food and partly by the time spent handling food. At high food density fish does not have to search for food at all and feeding rate is determined almost entirely by how fast the fish can handle its food. At these very high densities, fish, in effect, has "all the food it can handle."

The foraging and growth of walleye (*Sander vitreus*) in size 20-150 mm fed either zooplankton, benthic invertebrates, or fish over a range of prey densities. The number of each prey type consumed was influenced by walleye size and prey density. Walleye exhibited Type 2 functional responses on each prey type; attack coefficients were constant across zooplankton and fish densities but decreased with benthic invertebrate densities. Handling time estimates were greater for fish than for other prey types but similar for zooplankton and benthos. Foraging efficiencies on zooplankton and benthic invertebrates increased with walleye size but were variable for fish prey (Galarowicz and Wahl, 2005).

3. A sigmoid exploitation curve shows an increase in consumption, over a threshold density. At the threshold, the exploiter can locate the resource more efficiently than just by random encounter. With increasing resource density, consumption reaches a plateau. In some instances the exploiter may be capable of avoiding a given resource type unless it surpasses a threshold density that permits economical exploitation. Many fish seem to focus most of their attention on more abundant foods, switching to less common food only when it exceeds some threshold density. Fish may also require some learning to exploit food at a maximum rate. At low food densities they do not have sufficient exposure to a particular food item to fully develope their searching and handling skills. The optimal density of plankton required for the growth and development of *Coregonus lavaretus* (L.) larvae were to 200-260 individual food organisms/litre. The feeding optimum depends on density of plankton and water temperature and the time at which feeding begins (Dabrowski, 1976).

### 2.3 Nutrition value

Prey items may also be selected in relation to their value to the fish. If two different prey types are available, the forager would choose the nutritionally favorable prey. Large prey items yield more nutrition than small prey items. The larger payoff afforded by a larger prey item, the food consumed per unit capture and handling time might increase with increasing prey size until a maximum, beyond which capture time and handing time reduce the payoff. Small prey items are more suitable for eating than large prey because they are easier to manipulate and bite, which shortens the handling time per item. Optimal foraging theory assumes that predators use different prey to maximize their energetic gain. It has been usually assumed that the energetic value and the encounter rate are functions of prey size and, therefore, that predators prefer large prey, which offer more nutritional advantages (Charnov, 1976). In addition, when fish consumed nutritionally low quality food, they should ingest large amounts of such food and/or develop larger digestive chambers than those individuals consuming better quality foods (Sibly, 1981). Thus, the main objective is to predict the efficient foraging behavior or strategy that should maximize fitness or energy gain. This is the total energy gained per unit time by the forager minus the energy costs of foraging, and this clearly depends on the energy content of each prey type, the time it takes to encounter a prey of a given type, and the energy costs of searching for and capturing that prey type. From the foraging and growth of walleye (*Sander vitreus*), walleye fed either zooplankton, benthic invertebrates, or fish over a range of prey densities. The smallest walleye size class (20 mm) had similar energy return (J•min$^{-1}$) and growth (g•day$^{-1}$) on zooplankton, benthic invertebrates, and fish. For larger walleye, both energy return and growth were highest on fish, intermediate on benthic invertebrates, and lowest on zooplankton. Diet shifts of juvenile piscivore and growth can be explained by ontogenetic changes in foraging abilities and prey densities (Galarowicz and Wahl, 2005).

Many fish are flexible in their choice of foods, responding to changes in the availability or profitability of potential prey. Such flexibility confers important advantage in terms of both survival and mobility in estuaries. In term of prey selection, fish feeding type in three categories were proposed in Gerking (1994) and Elliott and Hemingway (2002).

1. Generalists – this species have no highly developed preference for a particular food source. They are not feeding selectively on a prey item which may be rare but feeding on available, usually abundant prey. Feeding on available prey not consider food size or food nutrition value which feeding type of this group not follow optimal foraging theory in energy lost and nutrition value uptake.

2. Specialists – most fish in this category concentrate their energies on a restricted type of food and rarely broaden their diet. Specialists are usually characterized by some feeding adaptations. Moreover, such species are better off when their preferred environment remains stable. They selected prey items which follow optimal foraging theory by emphasized nutrition value and energy in seek and eat food items.

3. Opportunists – this fish show the flexibility in feeding than generalists and can feeds on, a source of food outside its usual diet. Their diets are usually diversed. There was the lack of seasonal, tidal and temporal variations in feeding intensity. They are not restricted to certain feeding pattern, where prey are consumed when encountered. For example, the omnivore that switches between an animal and plant diet is an opportunist. The ability to take advantage of the most profitable food source at a particular time is called trophic adaptability. Fish in this group also change behavior and feeding types follow food items in environment thus this group have tactic for feeding in estuarine and mangrove forests through quantity and species of food items in day time and season. Thus, fish choose between alternative sources of food by weighing the benefits and costs of capturing one possible choice over the other. They are flexible in their choice of foods, responding to changes in the availability or profitability of potential prey. Such flexibility confers important advantage in terms of both survival and mobility in estuaries.

**3. Niche Shift**

Niche shift is a change in food selection in response to a physicochemical change in the environment or to a change in competitive pressure. Predation risk is one of the factors that cause a niche shift. Different fish sizes have similar feeding in similar portion food item. Occasionally, fish have several feeding type and portion in each stage whereas some fish select specific food item since larvae to adult. Feeding types also were selected by food source in nature, as fish consider to nutrition value and energy from quantity and size food item. Feeding of fish was categorized in three types.

1. Prey switch: Ontogenetic niche shift is defined as a change in habitat or resource use during development that provides the maximum possible benefit for an individual (Werner and Gilliam, 1984). Such discrete shifts in resource or habitat use have been well documented in species that metamorphose and in species in which morphology changes allometrically (Adams, 1996). In other systems, size related diet shifts are the result of size specific changes in foraging ability, which enable individuals to capture and consume progressively larger prey (Persson, 1990). The size of an animal can strongly influence its ability to avoid predators, to forage in a particular habitat or to forage on a specific prey type (Hambright, 1991). When ontogenetic niche shifts are relatively discrete, a population can be divided into separate size classes or stages based on diet or habitat use (Osenberg *et al*., 1994). Due to associated changes in the nature and intensity of intra- and interspecific interactions such as competition or predation, each stage may play a functionally different role in community or ecosystem level processes. However, separate stages are not independent of one another; they are linked together by processes of production and recruitment. Factors such as resource productivity or predation intensity that affect one stage are therefore transmitted to later stages, and eventually feed back to the original stage (Osenberg *et al*., 1992; Mittelbach and Osenberg, 1993). Ontogenetic diet change is common in fish. A fish may adopt several trophic roles in its lifetime.

Ontogenetic change have changed food types such as report of Parnichsuk and Tunvilai (1994) studied on food habits of red snapper, *Lutjanus argentimaculatus* from Klong Natab and Tepa Estuaries in Songkhla Province. Shrimp and worm were dominant prey items in fish size 2-3 cm TL. Mostly Caridea shrimp, *Penaeus* sp. and fish larvae were eaten by red snapper in size 3-5 cm. A morphological examination of the feeding apparatus suggested that the size of important prey items consumed was determined by gape height and jaw width. Prey available to different size classes of fish was determined by combining information on microhabitat use, foraging behaviors, and prey volumes in the substratum. Small fish showed a preference for ostracods whereas large fish selected for bivalves and crabs. Although polychaetes were the dominant prey item for all size classes, they were consistently selected against.

2. Diel change: day/night time change effect to distribute food source and feeding types of fish. The changes probably reflect changes in the activity and hence the vulnerability of the prey. Grossman *et al.* (1980) studied diel variations in gut fullness, diet and prey diversity for a California estuarine gobiid (*Lepidogobius lepidus* Girard). Gobiid in small (< 50 mm, SL) and large ($\geq$50 ml, SL) consumed similar prey types in different proportions. Dominant prey items were polychaetes, harpacticoid copepos, gammarid amphipods, molluscs and other crustaceans. Diets of large and small gobies were not significantly correlated and larger fish had a more diverse diet. Small fish fed at all times while larger gobies fed primarily at night. Changes in diet may be related to differential prey preferences, feeding chronologies, and increases in fish size. Colombini *et al.* (1996) reported the feeding behavior of *Periophthalmus sobrinus* in Kenyan mangrove. The mudskipper has a carnivorous diet and forages during both day and night although feeding greatly decreases after dark. Quantitative and qualitative differences in diet were found during the day and night of the two synodic and tidal phases. In addition, the mudskippers showed a tidal rhythm in feeding behavior with peaks of activity around low tide on spring tides and around high tide on neap tides. Darnaude *et al*. (2001) studied the diets of the four flatfish species, *Arnoglossus laterna*, *Bothus podas* (Bothidae), *Buglossidium luteum* and *Solea solea* (Soleidae) in the Gulf of Fos (north-west Mediterranean). The Soleidae were principally actived at night, meanwhile Bothidae actived during daytime. *A. laterna* and *B. luteum* mainly preyed on crustaceans, gastropod and bivalve whereas *B. podas* and *S. solea* preyed principally on polychaetes and bivalve.

3. Seasonal change: seasonal changes in food availability may be caused by changes in the habitats available for foraging, changes resulting from the life history patterns of food organisms and changes caused by the feeding activities of the fish themselves. Sribyatta (1996) studied stomach contents of anchovy, *Encrasicholina heteroloba* in the Western Gulf of Thailand. Copepod and diatoms were dominanted prey items in February and nematode as the main prey items in May. Labropoulou *et al*. (1997) found striped red mullet, *Mullus surmuletus* in the Cretan shelf (north-eastern Mediterranean) have diets varied seasonally. Decapods were prey items in summer. Mostly amphipods were prey items during winter and spring. The morphological characteristics and the foraging behavior of *M. surmuletus* account for both prey type selection and the feeding pattern.

## 4. Feeding in Various Stages of Fish

### 4.1 Larval feeding

The larval period of fish includes both the yolk sac stage when the just-hatched larva carries its own food supply in the form of energy-rich yolk and the larval stage after the yolk sac has been absorbed and before metamorphosis into the juvenile stage occurs (Blaxter, 1969). In some species the mouth opens in the yolk sac stage, and external feeding commences at that time. The larvae are then clearly using both external and internal sources of energy for metabolism (Balon, 1975).

Size selection also attracts considerable attention, because the larvae do not follow the same pattern of optimal foraging theory as do adults. Given an opportunity to feed on a wide size range of prey, all of which they can consume, the larvae select intermediate-sized zooplankters over the long term, whereas adults select the larger sizes. Typically, maximum and median lengths of consumed prey were considerably less than fish mouth gapes (Gerking, 1994). Food size of larvae was followed weight, length and mouth gape of larvae. The relationship between prey size and mouth gape exhibits in Figure 3.9 The mouth gape determined size and density of food particles as related to growth in three ontogenetic stages (Houde, 1997):

Stage 1 slow growth with an increase in particles density of a constant size per gut.

Stage 2 rapid growth during a time at constant particles density but particle size increases.

Stage 3 rapid growth when particle density increases again but the size of particles remains the same.

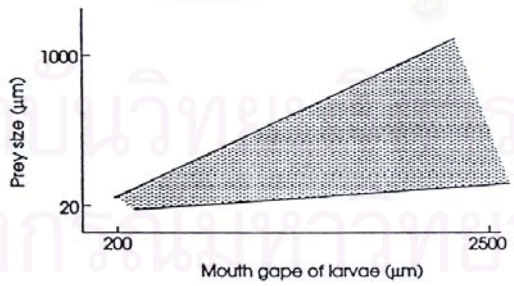



Figure 3.9 Conceptual relations between prey size and mouth size of fish larvae (Houde, 1997)

In nature, fish larvae often encounter the starvation period. At some point, the starvation may be severe as “Point-of-no-return”. This is the point where only 50% of the larvae are still able to feed, if food becomes available. When the larvae often experience a critical period of starvation, the digestive tract and its associated glands are the first organs impaired by food deprivation (Theilacker, 1978).

### 4.2 Juvenile feeding

For many species in tropical estuaries, the diet of juveniles is markedly different from that of the adults. In this case the diets of juveniles, and the ontogenetic changes themselves, may be specialized and directly related to living in estuaries. The actual timing of switches in diet usually relates to juveniles becoming adults, or may be related to changes in morphology of jaws or teeth or size. Mouth gape showed important determinant of prey size (Peterson and McIntyre, 1998). Although increased gape height and width were associated with increased size of the most important prey items, the maximum size of prey consumed was not constrained by either mouth gape or pharyngeal gape in this species. It is possible, however, that the ability to handle large prey items was reduced in smaller fish, thus making it more efficient to select smaller prey items. Diets also differ for the same species at different locations and between size classes of a species at the same location.

Size related morphological changes are important in relation to many aspects of the feeding apparatus of fish. These include jaw length, gape height and width (Platell *et al*., 1998), inter-gill raker distances (McCormick, 1998) and position and protrusibility of the mouth (Eggold and Motta, 1992). However, size related morphological changes in the efficiency with which a prey item is captured and consumed may also indirectly influence prey selection (Wainwright and Richard, 1995). For example, the stomach contents of croaker (*Micropogonias undulates*), show a great variation with size of fish, indicating ontogenetic changes in diet. (Sheridan and Livingston, 1979). Fish between 10 and 70 mm eat mostly polychaetes (>60%), detritus and insect larvae, as well as a diversity of other minor items such as amphipods, mysids, harpacticoid copepods and calanoid copepods. For larger fish between 100 and 150 mm, the number of prey items decreases and shift to include polychaetes, shrimps, chironomids, juvenile fish and a small but variable amount of detritus. Prey available to different size classes of fish was determined by combining information on microhabitat use, foraging behaviors and prey volumes in the substratum.

Furthermore, the timing and extent of changes in food and feeding ecology are often associated with changes in life style or habitat. Habitat type is also an important factor influencing the feeding strategy of a species by determining foraging opportunities. Fish may have to choose between a habitat that provides more abundant and diverse prey, but in which prey is harder to capture, and a habitat which has less prey, but better capture opportunity (Crowder and Cooper, 1982). For most species, larger fish eat larger prey and hence there will be a gradual change in the size of prey as the fish grows (Dall *et al*., 1990). This is in accordance with the theory of optimal diet, which predicts increasing specialization in the diet with increase of absolute abundance of preferred food types in the environment.

**4.3 Adult feeding**

Adult fish often feeding followed optimal foraging theory and have niche shift for adaptations that maximize energy intakes (Brown, 1985). Fish foraging rates have also be found to decrease with increased fish size (McCormick, 1998). Changes in size of the feeding apparatus have also been associated with changes in foraging behavior and microhabitat use, thus altering the range of exploitable prey items. Size dependent factor complicates these interspecific interactions. The morphological differences between adult fish that allow the species to exploit different types of prey develop during the growth of the fish. Most fish feed on a limited range of prey types but dietary flexibility is a feature of many families. Such as flexibility confers important advantages in terms of both survival and mobility in estuaries where there may be large fluctuations in the type and numbers of prey available. For example, Lukoschek and McCormick (2001) studied food types and food size of *Parupeneus barbernius* in varies size classes. *Parupeneus barbernius* forages on benthic invertebrates using a wide range of foraging modes. Polychaetes were the most important prey item for all size classes, but fish less than 120 mm total length consumed smaller ostracods and nematodes than did larger fish. Fish greater than 120 mm total length consumed bivalves, and fish over 240 mm total length consumed mostly bivalves and crabs.

**5. Feeding Behavior and Preference**

Fish larvae have feeding behavior in three stages: 1. encounter of a single prey, 2. attack and 3. ingestion before moving on to another victim. After locating the prey, the larva moves to within striking range (fixation) and then snaps at the prey from an S-shaped position of the trunk of the body (Gerking, 1994). Ontogeny of the sense organs and behavior is important to feeding and predator avoidance of fish larvae at sea (Blaxter, 1986). Changes in larval behavior are closely related to the development of the sense organs in marine fish. Most fish larvae show positive phototaxis towards an artificial light source at the time of first feeding, Chemoreception is also important to feeding larvae (Fuiman and Magurran, 1994). Taste buds allow fish to choose among prey items and food preference has been observed in the larvae. Most fish larvae are dependent upon vision for prey detection (Blaxter, 1986) although non visual senses implicated in prey detection by selective planktivorous fish larvae (Salgado and Hoyt, 1996). This is in contrast to the non selective particulate mode of feeding displayed by juveniles and adults of some fish species, in which gill rakers are used to filter prey from the environment without prior discrimination of individual prey (Batty *et al*., 1986).

The predation cycle of juveniles and adults feeding behavior consist of 1. encountering the prey (search time) or orientation, 2. positioning and persuit, 3. attack and capture, 4. ingestion and 5. digestive pause before engaging in another bout of feeding. The last four items in the list are called handling time. Pursuit of the prey, its capture and ingestion, and a digestive pause could possibly consume a considerable period of time (Gerking, 1994). The sequence of behaviors a predator might be expected to show, together with factors potentially influencing them (Endler, 1991). Internal factors of fish include its morphology, its capacity to learn and its current physiological state. For example, since adult *C. analis* were suction dominated feeders (Norton, 1991). There were two possible ontogenetic trajectories that could be seen in the juvenile stage. One was that the juveniles were also suction-dominated feeders and showed no change during the juvenile period. This would indicate that feeding mode either remained constant throughout ontogeny or changed during the larval stage. A second possibility was that juveniles showed a different feeding mode from that of adults and that development of the adult feeding mode occured during the juvenile period. External factors deriving from the prey are all those features that the prey has evolved to avoid and evade capture. Predation risk and risk of parasitic infection are examples of external biotic factors, whereas environmental factors are examples of abiotic external factors. Other factors beside translucence and motion are 1. shape of the prey, 2. luminescence contrast of the prey, 3. color and 4. orientation of the predator and prey, wherein peripheral vision of the predator may be less acute than head-on orientation. Because of the multiple factors that affect reactive distance, an investigator must be aware of the complicating elements that may enter into observations. All factors have never been incorporated into a single model that predicts reactive distance. All these will influence the cycle of to overcome the prey's defences. Therefore, feeding behavior is a complex behavior that encompasses several behavioral responses associated with eating, including modes of feeding and feeding habits, mechanisms of food detection, frequency of feeding, and food preferences. Fish feeding habits range from plant and detritus feeders, to predatory feeders, in a wide range of ecological habitats. Some fish are generalists in terms of prey items, others are highly specialized, and some are opportunists. In general, hunger stimulates feeding behavior, with increased searching and decreased handling time of prey items under hunger conditions, whereas fish feed more selectively and slowly as a meal proceeds.

## C. Materials and Methods

### 1. Morphological Study

Spotted scat from the mangrove plantations sites (PP1-PP3) and estuary sites (PP8-PP9) were collected by using the plankton net 103 and 330 μm mesh, the push net 2 mm mesh size, trawl net 3 mm mesh size and the gill net 1 cm mesh size during low tide at day time. Spotted scat of total 50 individuals in each size namely 1-2 cm, 2.1-8 cm and >8 cm were randomly taken from the catch. Fish measurement namely total length (TL), standard length (SL), head length (HL), body depth (BD), width of the mouth gape (WID) and wet weight were carried out. Fish further preserved in 10% neutral formalin. Feeding structure morphology in fish were examined namely mouth position, teeth, gill rakers, shape of stomach, number of pyloric caeca and intestinal length to compare relationship of intestinal length/total length. Feeding morphological data sheet of fish was showed in appendix 2.1.

### 2. Stomach Content Analysis

#### 2.1 Food spectrum

Spotted scat collected from the mangrove plantations sites (PP1-PP3) and estuary sites (PP8-PP9) total of up to 40 individuals of each stations from the monthly samples were randomly taken from the catch. Fish were measured in total length (TL) and weigh in wet weight. After dissection, the stomach contents were determined by microscope examination. Only full stomachs or nearly full of identifiable prey items were examined. Prey items were identified to taxon with results presented as prey items in diet composition. Enumeration of prey items followed the method of Williams (1981). The following percentages were calculated for each prey items.

$$P = (F/A) \times 100$$

where P represents percentage points of each food item; F represents total points of each food item and A represents total points of all food item

The results from percentage points of each prey items were tested using a one-way analysis of variance (ANOVA) revealed a significant interaction between stations in high salinity, independent simple *t*-test was used to compare the prey items between low and high salinity. Prior to the analyses, data were transformed to $[\log_{10}(x+1)]$ the normality of distribution. The calculated coefficients were compared to the correlations coefficients at significance level of $p < 0.05$.

**2.2 Index of relative importance (IRI)**

The main food items were identified using the index of relative importance (IRI) of Pinkas *et al*. (1971), as modified by Hyslop (1980). IRI in stomach content of total spotted scat and tade mullet was describe feeding selection in each station and salinity.

$$IRI = (Cn + Cv) \times F$$

where IRI represents index of relative importance of the main food items, taxa or ecological groups; C*n* represents percentage numerical abundance as the total number of food items in all stomachs in a sample; C*v* represents percentage volumetic composition as the total volume of that taxa of prey and *F* represents percentage frequency of occurrence based on the number of stomachs in which a food items was found.

**2.3 Food quality (C:N ratio)**

Organic matter in stomach content of spotted scat in three stages was analyzed according to ASTM D 5373-02 and ASTM D 5291-02 method by using a Perkin Elmer PE 2400 Series II CHNS/O Analyzer. The analysis is by catalytic combustion followed by a packed gas-chromatographic column separation and quantitative determination by thermal conductivity detector. Samples were oxidized at 975°C in a pure oxygen environment using several metal oxides as catalysts. The gases mixture ($CO_2$, $H_2O$ and $NO_x$) were produced and passed over elemental copper in a reactor tube to reduced $NO_x$. The result described sources of organic content in stomach of spotted scat.

**3. Feeding Behavior Preference**

Feeding behavior preference experiment was conducted by using spotted scat in size 1-2 cm, 2-7 cm and larger than 8 cm. Two replication of 5 fish in a 4 litre pond for larvae, 12 litre pond for juveniles and 18 litre pond for adults were tested for each size. During the test, filtered seawater at salinity 20 psu was used. Water quality was monitored. Dissolved oxygen was continuously supplied. Fish were starved for one day before experiment. Each pond was provided with different food. For fish larvae, different shapes of microphytoplankton namely *Chaetoceros* sp. and *Skeletonema* sp. in certain quantity were given. For juveniles and adults, rotifer in certain quantity and microphytoplankton were provided. All experiments were conducted for 24 hour as shown Figure 3.10.

| | | |
|---|---|---|
| Experiment 1 (2 replications) | Fish larvae+ | *Chatetoceros* sp. |
| | | *Skeletonema* sp. |

| | | |
|---|---|---|
| Experiment 2 (2 replications) | Juveniles + | *Chatetoceros* sp. |
| | | *Skeletonema* sp. |
| | | Rotifer |

| | | |
|---|---|---|
| Experiment 3 (2 replications) | Adults + | *Chatetoceros* sp. |
| | | *Skeletonema* sp. |
| | | Rotifer |

Figure 3.10 Experimental design on the experiment on feeding preference in spotted scat

Feeding behavior of spotted scat in all stages was studied during feeding preference experiments. Before and after feeding, behaviors of spotted scat were examined. Food was provided manually from the side of the pond. Vedio recording were replayed enable types of behavior exhibited by feeding spotted scat to be identified and described qualitatively. The frequency of each type of behavior was recorded manually during 24 hr. Feeding preference experiments were calculated from number of food items before feeding (0 hr) and after feeding (24 hr) by Manly's Alpha Preference Index (Krebs, 1989) the formula on estimating alpha is

$$\alpha_i = \frac{Log Pi}{\sum_{j=1}^{m} Pj}$$

Where $\alpha_i$ = Manly's alpha (Preference index) for prey type *i*

*Pi*, *Pj* = Proportion of prey *i* or *j* remaining at the end of the experiment ($i$ = 1, 2, 3,…, $m$; $j$ = 1, 2, 3,…, $m$) = $e_i/n_i$

$e_i$ = Number of prey type *i* remaining uneaten at end of experiment

$n_i$ = Initial number of prey type *i* in experiment

$m$ = Number of prey types

## D. Results and Discussions

### 1. Morphological Adaptations for Feeding in Spotted Scat

Spotted scat were classified to be omnivorous fish due to the morphology of feeding structure such as mouth morphology, teeth, gill rakers and digestive tract. Feeding structure morphology of spotted scat also corresponded to previous studied by Vitheesawat (1999) at Tha-Chin mangrove forest.

#### 1.1 Mouth shape and position

Spotted scat in each stage has subterminal mouth that showed benthic feeding habit. The average width of mouth gape was 0.12-0.61 cm from larvae to adults (Table 3.1, 3.2). The ingestion in fish larvae is limited by the mouth gape. At the beginning of feeding, prey is more selected by size than taste or other factors. Most larval stage begins feeding on large microphytoplankton and small zooplankton and follow by feeding on increasingly larger zooplankton in juvenile stage. Fish larvae are able to ingest prey with similar size to mouth gape. Prey/gape ratio of 25–50% seems to be the most appropriate (Østergaard *et al*., 2005). Rapid increase of jaws and gape during the first few days helps the larvae to increase size of prey and ingestion (Olsen *et al*., 2000). The actual timing of switches in diet usually relates to juveniles becoming adults, mouth gape show to be an important determinant of prey size (Peterson and McIntyre, 1998). These include jaw length, gape height and width (Platell *et al*., 1998).

#### 1.2 Teeth

Spotted scat teeth are mainly villiform type, small and slender teeth forming in the fish larva was a band, appear in 1-2 rows on the upper and lower jaw and reached 5-6 to 6-7 rows in adult. Juvenile and adult have ciliiform teeth on tongue for crush or grind food (Table 3.2). The development of teeth on the jaw means that the food items must be easily captured and digested independently of these mechanisms. Many omnivorous fish have villiform, small canines or have lost them through evolutionary tooth reduction. For example, juvenile *Lates calcarifer* has villiform teeth when analysis of stomach content found microphytoplankton, small fish and shrimp (FAO, 1988). The teeth on the edges of the jaws are for catching and chewing the prey, while the pharyngeal teeth stop the prey from escaping. Mollusk and crustacean feeders possess short, heavy dentition and zooplankton feeders have the least developed dentition.

**1.3 Gill rakers**

Spotted scat have short gill rakers varied from 13-20 slits. The average number of gill rakers was 15.00±0.13 in larvae, 16.98±0.15 in juveniles and adult of 17.00±0.21 (Table 3.1, 3.2). Although, the fish consume benthic phytoplankton, zooplankton and microcrustaceans they seem to pick them up rather than filter them. Plankton feeding fish always possess well-developed gill rakers. Kramer and Bryant (1995) concluded that omnivore of several species tended to consume more plants as they grew. Moreover, a reduction in the number of the gill rakers is related to a more benthic feeder. Such a reduction is an advantage for the species that live close to the substrate and stir up mud. If the gill raker slits closed tightly, the suspended particles would be swallowed, whereas instead, they are eliminated more easily.

**1.4 Digestive system**

The stomach appeared U-shape in all stages. U-shape stomach could containe large volume of food to digest. The stomach size also related to prey size that the fish consumed, the stomach being largest in species that consume large, single food items or sporadically eat high volumes of food, whereas the stomach is smaller in planktivores that feed much more frequently or almost continuously.

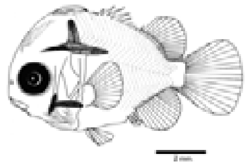
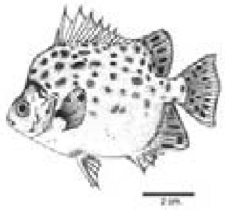
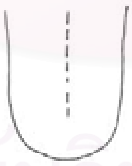
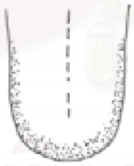
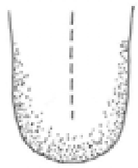
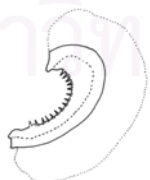
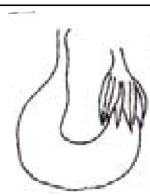
The number of pyloric caeca of spotted scat varied 7-22 pieces (Table 3.2). The number of pyloric caeca has correlated with the length of the fish. As fish grew up, the number of pyloric caeca also increased. Average numbers of pyloric caeca were found 10.52±0.26, 15.74±0.29 and 16.10±0.28 in larvae, juveniles and adults respectively (Table 3.1). In certain species the numbers of caeca have correlated with the bulk of food consumed. The function of pyloric caeca was an adaptation to increase the absorption surface, the nutrient uptake capacity of the gut and allowed to optimize digestion of diversed food items. The inner wall of fish pyloric caeca are also extensively folded resulting the presence of large numbers of villi of mucosa (Rust, 2002). These properties facilitate the enzymatic breakdown of proteins, hydrolysis of lipids, absorption of amino acids, fats, water, sodium and other nutrients (Toyota *et al*., 2002). The food passes the stomach and enters the intestine via the pyloric sphincter. The sphincter function as physically separates the stomach from the intestine and prevents the passing of food.

The ratio of intestine length/standard length varied from 0.59-1.88 in larval stage, 0.63-4.29 of juvenile stage to 2.31-4.17 in adult stage (Table 3.1). Stomach and the gut length of fish means that a limited number of food items can be taken at once, and these items are unlikely to be retained for a lengthy period of time in the gut. As a result their digestion must be rapid and feeding must occur often to ensure sufficient provision of nutrients.

Table 3.1 Comparative measurement on feeding structure morphology of spotted scat (n=50)

| **Structure morphology** | **Larvae** (Mean±SE) | **Juveniles** (Mean±SE) | **Adults** (Mean±SE) |
|---|---|---|---|
| Total length (TL) (cm.) | 1.17-1.84 | 2.05-7.44 | 8.50-20.00 |
| Average total length (TL) (cm.) | 1.49±0.02 | 4.41±0.23 | 11.18±0.35 |
| Standard length (SL) (cm.) | 1.11±0.01 | 3.41±0.18 | 8.89±0.28 |
| Body depth (BD) (cm.) | 0.72±0.01 | 2.24±0.12 | 5.37±0.14 |
| Head length (HL) (cm.) | 0.55±0.01 | 1.41±0.07 | 3.08±0.07 |
| Width of the mouth gape (WID) (cm.) | 0.12±0.001 | 0.19±0.004 | 0.61±0.01 |
| Intestine length (cm.) | 1.51±0.06 | 9.35±0.70 | 28.31±0.78 |
| Wet weight (g.) | 0.10±0.003 | 3.49±0.43 | 44.54±4.06 |
| Head length/body depth | 0.65-0.86 | 0.57-0.75 | 0.50-1.19 |
| Head length/total length | 0.34-0.42 | 0.29-0.37 | 0.20-0.31 |
| Body depth/total length | 0.44-0.52 | 0.47-0.55 | 0.17-0.54 |
| Total length/body depth | 1.92-2.25 | 1.82-2.13 | 1.85-5.95 |
| Intestine length/total length | 0.44-1.42 | 0.49-3.37 | 1.83-3.37 |
| Intestine length/standard length | 0.59-1.88 | 0.63-4.29 | 2.31-4.17 |
| Number of gill rakers | 15.00±0.13 | 16.98±0.15 | 17.00±0.21 |
| Number of pyloric caeca | 10.52±0.26 | 15.74±0.29 | 16.10±0.28 |

Table 3.2 Comparative study on feeding structure morphology of spotted scat

| Characteristic | Larvae | Juveniles | Adults |
|---|---|---|---|
| **Body form** |  |  |  |
| **Mouth position**<br>(subterminal mouth) |  |  |  |
| **Teeth on upper jaw** | <br>Villiform teeth<br>1-2 rows | <br>Villiform teeth<br>4-5 rows | <br>Villiform teeth<br>5-6 rows |
| **Teeth on lower jaw** | <br>Villiform teeth<br>1-2 rows | <br>Villiform teeth<br>4-5 rows | <br>Villiform teeth<br>6-7 rows |
| **Teeth on tongue** | <br>Not found | <br>Ciliiform teeth | <br>Ciliiform teeth |
| **Gill rakers** |  |  |  |
| **Shape of stomach** | <br>U-shape | <br>U-shape | <br>U-shape |

**2. Stomach Content Analysis**

**2.1 Food spectrum**

The dominant food items of spotted scat were microphytoplankton namely Bacillariophyceae, pennate diatoms, and Cyanophyceae, *Oscillatoria* spp. Protozoa, *Zoothamnium* spp., were found second in rank. Zooplankton, detritus and benthos were also found. The dominant pennate diatoms were *Pleurosigma/Gyrosigma* spp. and *Nitzschia* spp. Pennate diatoms was found at high density in stomach of all stages of the fish obtained from mangrove forests during high salinity, while *Oscillatoria* spp. was found in highest density during low salinity. However, the prey items found in all fish were not significantly different between low and high salinity ($p$>0.05) (Figure 3.11).

Main prey items found in larvae were namely microphytoplankton, protozoan and zooplankton. These preys were with the average size less than the width of the mouth gape of the larvae such as average size of *Pleurosigma* were 117.71 µm in length and 20.68 µm in width and *Nitzschia* spp. were 67.56 µm and 10.63 µm in length and width respectively. The size measurement of these microphytoplankton were enumerated from 30 cells each. Zooplankton such as rotifers have average size of 100 µm width and cirripedia larvae have maximum size of were 0.9 mm. Dominant prey items of juveniles similar larvae meanwhile benthos, insects and detritus were increasing. However, pennate diatoms were also dominant in adults. The stomachs of adult spotted scat from mangrove fringe and estuarine waterway found the increase in benthos, *Onchidium* egg and taniadacean, and detritus. As the salinity in the estuary was low, *Zoothamnium* spp. increased in the stomach of adult spotted scat. Protozoan can be found in 97% of spotted scat stomachs examined. The different components of the diets for spotted scat collected from the mangrove forests and the estuary were similar. Food components in spotted scat did not showed significant difference ($p$>0.05) due to salinity and habitat.

Spotted scat showed broad diets, being omnivore similar to the previous studies. Spotted scat diets in the mangrove forests in Phangnga and Surat Thani Provinces were mainly comprised of detritus, algae tissue, plant, diatoms, rotifer, foraminiferan, nematode, polychaete, mollusc, insect and fish (Monkolprasit, 1994). Musikasung *et al*. (2006) reported that the dietary compositions were algae, arthropod, fish and polychaete. However, the spotted scat collected from the Tha-Chin mangrove estuary, Samut Sakhon in the inner Gulf of Thailand were detritivore. Detritus content was found more than 81% of the total stomach content screening. Crustacean fragments namely amphipods, mysids, copepods, diatoms, polychaetes and fish scales were also observed (Vitheesawat, 1999).

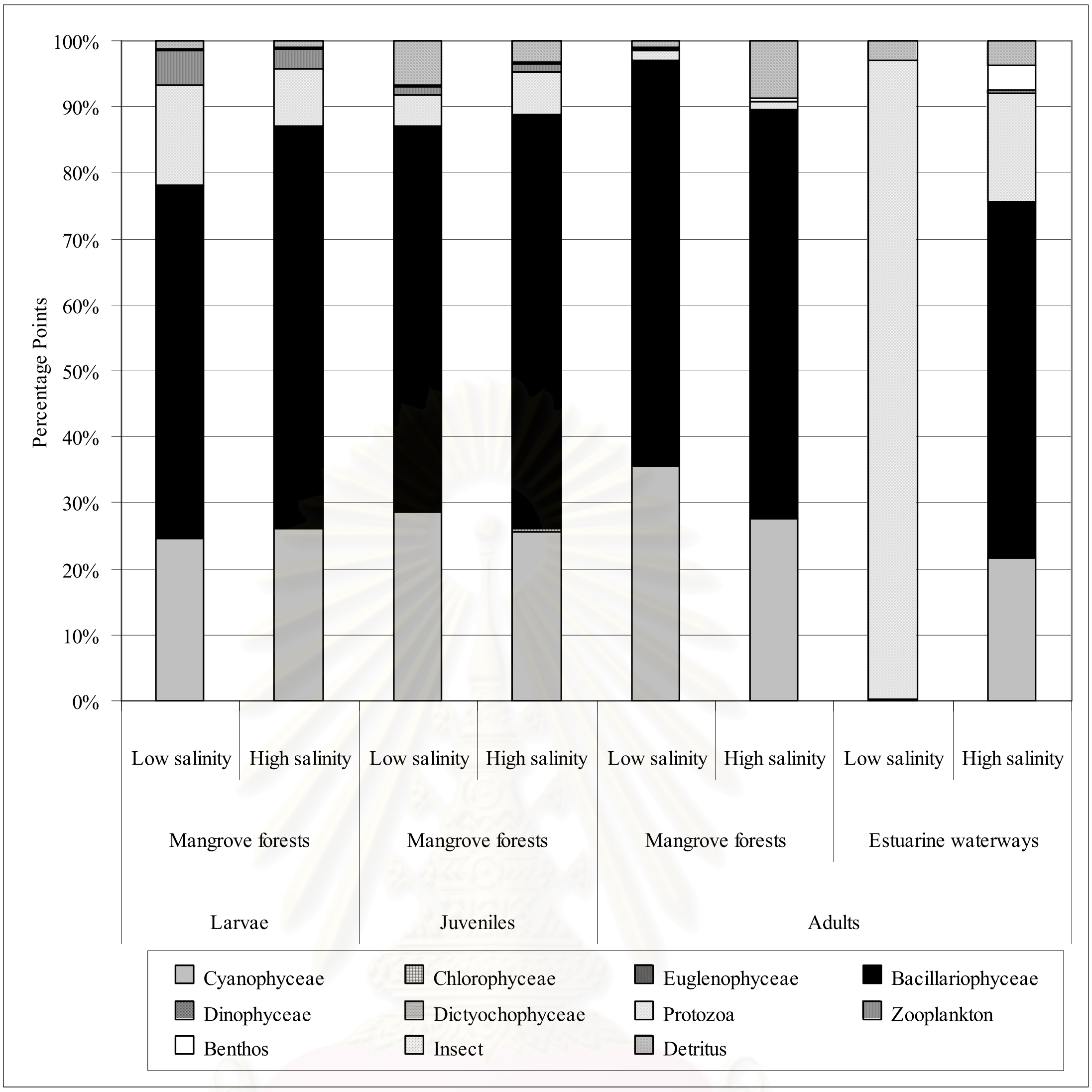



Figure 3.11 Dietary components in spotted scat in mangrove forests and estuarine waterways in Pak Phanang Estuary, Nakhon Si Thammarat Province

2.2 Index of relative importance

Cyanophyceae, Chlorophyceae, Euglenophyceae, Bacillariophyceae, Dinophyceae, Dictyochophyceae, protozoa, zooplankton, benthos and detritus were found in the spotted scat larvae stomach content in low and high salinity periods. Microphytoplankton were predominant prey items in low and high salinity periods in mangrove forests. Pennate diatoms were found approximately 60% and *Oscillatoria* spp. were found 24% of total prey items. (Table 3.3, Figure 3.12-3.13). There was no significant different of food items between low and high salinity. From the results, food items in the stomach of the larvae showed correlation between larvae distribution and abundance of food sources in mangrove forests. Spotted scat larvae utilized structural complexity in mangrove forest such as tidal channels and mangrove creeks, to provide shelters and feeding ground. Mangrove forests supply the enormous and continuous amount of food source for the larvae in order to support their high rate of metabolism and growth.

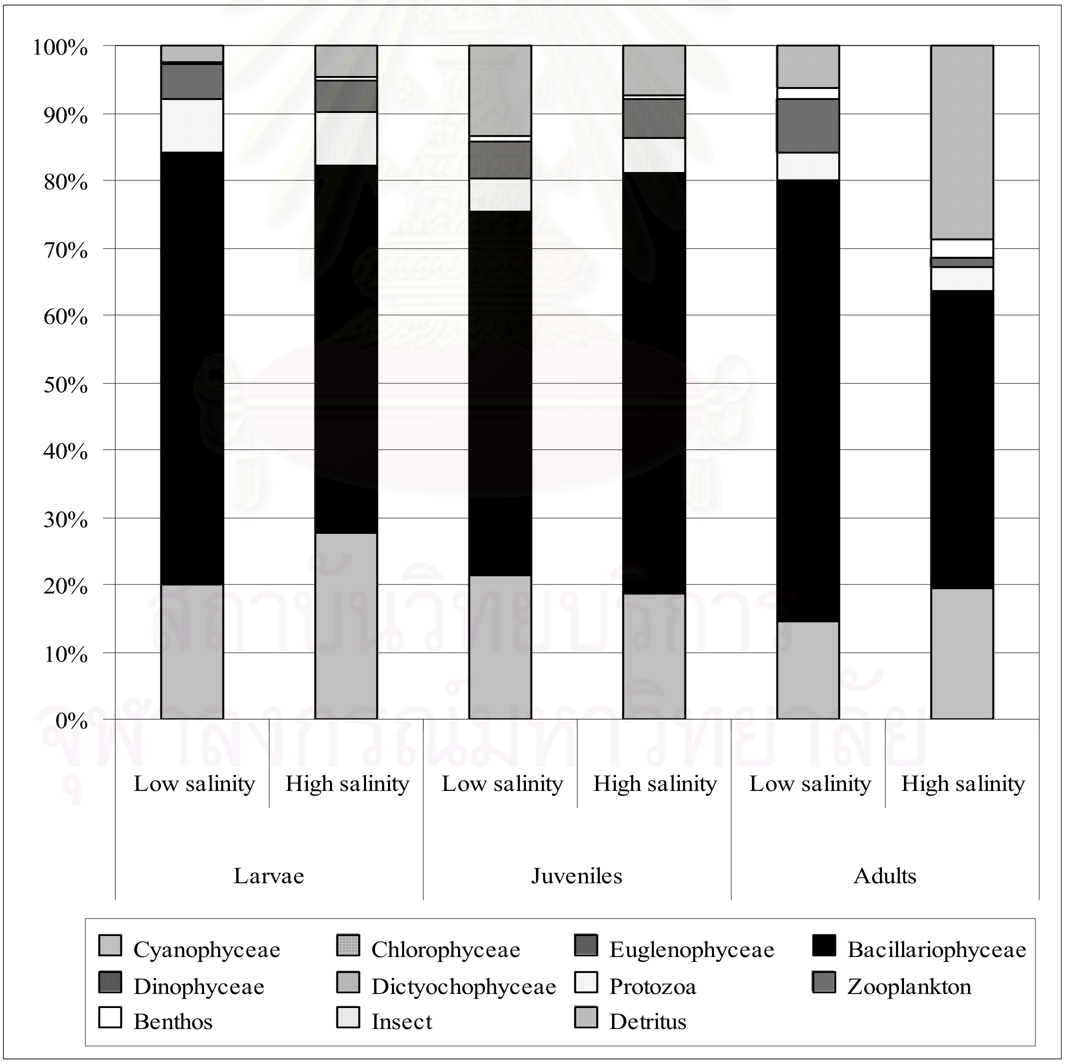



Figure 3.12 Comparative prey items in three spotted scat stages in Pak Phanang mangrove forests

In the case of juvenile spotted scat, microphytoplankton was the dominant in stomach content with protozoan, zooplankton, benthos, insect and detritus found in less amount. During both low and high salinity periods in mangrove forests, the major prey item was pennate diatoms of approximately 59% of the total prey items. *Oscillatoria* spp. was second in rak of 20%. Next selected prey consumed as detritus of 13% in low salinity while *Obelia* was selected during high salinity period (Table 3.4, Figure 3.12 and Figure 3.14). Prey items in juvenile stomach that showed correlated to the distribution and abundance of juvenile spotted scat which utilize Pak Phanang mangrove forest for habitat, shelter and food sources. Several researches on the diet composition of spotted scat in mangrove forests were consistented with this study such as Boonruang *et al.* (1994); Monkolprasit (1994) and Vitheesawat (1999) reported juveniles spotted scat diets in the mangrove forests comprised of detritus, algae tissue, plant, diatoms, rotifers, foraminiferan, nematodes, amphipods, polychaetes, molluscs, arthropods, insects and fish. Crustacean fragments namely mysids, copepods and fish scales were also found.

Bacillariophyceae, *Nitzschia* spp. and *Pleurosigma/Gyrosigma* spp., were the major prey items in adult spotted scat in low salinity of 63% and 44% respectively. Detritus was next prey items during high salinity total 29% of total prey items (Figure 3.12). Pennate diatoms was chosen as the first diet preference in low and high salinity periods in mangrove forests. While *Zoothamnium* spp. as firstly consumed during low salinity in the estuarine waterways. Zooplankton, benthos and detritus were also chosen in both salinity in mangrove forests and estuarine waterways (Table 3.5 and Figure 3.15-3.16). Adult spotted scat mostly distributed in the Pak Phanang Bay and coastal area. They often come into Pak Phanang mangrove forests as feeding ground. Distribution and abundance of adult spotted scat showed clearly correlated to food sources. In estuarine waterways during low salinity, *Zoothamnium* spp. were dominant in both estuarine waterways and fish stomachs. Arrunyagasemsuke (1975) studied the stomach content in spotted scat in size 9.3-18.6 cm collected from coastal area of Chonburi Province, hydroids, amphipods, lucifers and copepods were the major prey items. Musikasung *et al*. (2006) reported in stomach content in spotted scat in size 10.0-13.9 cm, being omnivorous. The stomach content consisted of 2.00% algae, 2.46% arthropod, 1.01% fish and 0.24% polychaete. In the stomach of spotted scat size 14.0-21.5 cm, zooplankton and benthos increased of 1.18% algae, 1.09% arthropod, 0.74% fish and 0.39% mollusk.

Table 3.3 List of prey items identified in spotted scat larvae stomachs at different salinity from mangrove forests and index of relative importance (IRI) value (C*n* = percentage numerical abundance, C*v* = percentage volumetric composition, *F* = percentage frequency of occurrence)

| **Prey items** | **Low salinity : Mangrove forests** | | | | **High salinity : Mangrove forests** | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Cn*** | ***Cv*** | ***F*** | **IRI** | ***Cn*** | ***Cv*** | ***F*** | **IRI** |
| *Anabaena* | 0.344 | 0.082 | 50.000 | 21.308 | - | - | - | - |
| *Oscillatoria* | 24.247 | 7.752 | 100.000 | 3199.919 | 26.045 | 21.939 | 97.778 | 4691.770 |
| *Actinastrum* | - | - | - | - | 0.001 | 0.033 | 11.111 | 0.377 |
| *Phacus* | 0.001 | 0.003 | 6.667 | 0.026 | 0.003 | 0.001 | 2.222 | 0.010 |
| *Strombomonas* | - | - | - | - | 0.002 | 0.000 | 1.111 | 0.003 |
| Centric diatoms | 3.272 | 0.619 | 100.000 | 389.101 | 1.534 | 1.151 | 96.667 | 259.543 |
| Pennate diatoms | 50.062 | 48.696 | 100.000 | 9875.751 | 59.476 | 30.358 | 100.000 | 8983.361 |
| Dinophyceae | 0.090 | 0.012 | 33.333 | 3.394 | 0.125 | 0.058 | 35.556 | 6.495 |
| *Dictyocha* | - | - | - | - | 0.002 | 0.000 | 1.111 | 0.003 |
| Tintinnids | 3.248 | 0.939 | 70.000 | 293.072 | 2.483 | 2.338 | 96.667 | 466.054 |
| Foraminiferans | 0.038 | 0.105 | 10.000 | 1.432 | 1.402 | 0.308 | 16.667 | 28.499 |
| *Zoothamnium* | 12.058 | 6.231 | 53.333 | 975.417 | 4.787 | 4.571 | 87.778 | 821.372 |
| Siphonophore | - | - | - | - | 0.001 | 0.004 | 1.111 | 0.006 |
| *Obelia* | 0.190 | 10.338 | 26.667 | 280.748 | 0.136 | 6.898 | 18.889 | 132.863 |
| Rotifer | 0.212 | 0.551 | 46.667 | 35.599 | 0.192 | 0.253 | 63.333 | 28.178 |
| Cladocera | - | - | - | - | 0.001 | 0.012 | 3.333 | 0.044 |

Table 3.3 (Continued)

| **Prey items** | **Low salinity : Mangrove forests** | | | | **High salinity : Mangrove forests** | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Cn*** | ***Cv*** | ***F*** | **IRI** | ***Cn*** | ***Cv*** | ***F*** | **IRI** |
| Ostracod | - | - | - | - | 0.001 | 0.002 | 3.333 | 0.010 |
| Cirripedia larvae | 4.319 | 13.678 | 23.333 | 419.927 | 0.187 | 3.929 | 54.444 | 224.114 |
| Copepod norplii | 0.118 | 0.442 | 26.667 | 14.933 | 1.976 | 6.345 | 45.556 | 379.085 |
| Copepod | 0.069 | 0.859 | 50.000 | 46.416 | 0.187 | 0.983 | 37.778 | 44.206 |
| Zoea of brachyura | 0.234 | 1.469 | 16.666 | 21.384 | 0.161 | 1.181 | 8.889 | 8.769 |
| Nematode | 0.091 | 0.209 | 43.333 | 13.030 | 0.069 | 0.257 | 51.111 | 16.622 |
| Polycheate larvae | 0.001 | 0.062 | 3.333 | 0.208 | 0.004 | 0.049 | 3.333 | 0.176 |
| Polychaete | 0.032 | 1.951 | 23.333 | 46.250 | 0.040 | 0.346 | 17.778 | 6.866 |
| Gastropod larvae | - | - | - | - | 0.076 | 0.850 | 18.889 | 17.494 |
| Bivalve larvae | 0.001 | 0.077 | 3.333 | 0.261 | 0.007 | 0.871 | 23.333 | 20.484 |
| Amphipod | 0.006 | 0.685 | 6.667 | 4.604 | 0.008 | 0.960 | 6.667 | 6.451 |
| Isopod | - | - | - | - | 0.004 | 1.373 | 2.222 | 3.060 |
| Plant tissue | 0.813 | 1.202 | 43.333 | 87.333 | 0.559 | 5.360 | 42.222 | 249.916 |
| Crustacean fragments | 0.516 | 3.885 | 66.667 | 293.409 | 0.218 | 4.662 | 51.111 | 249.395 |
| Fish scales | 0.037 | 0.154 | 46.667 | 8.910 | 0.314 | 4.907 | 57.778 | 301.692 |

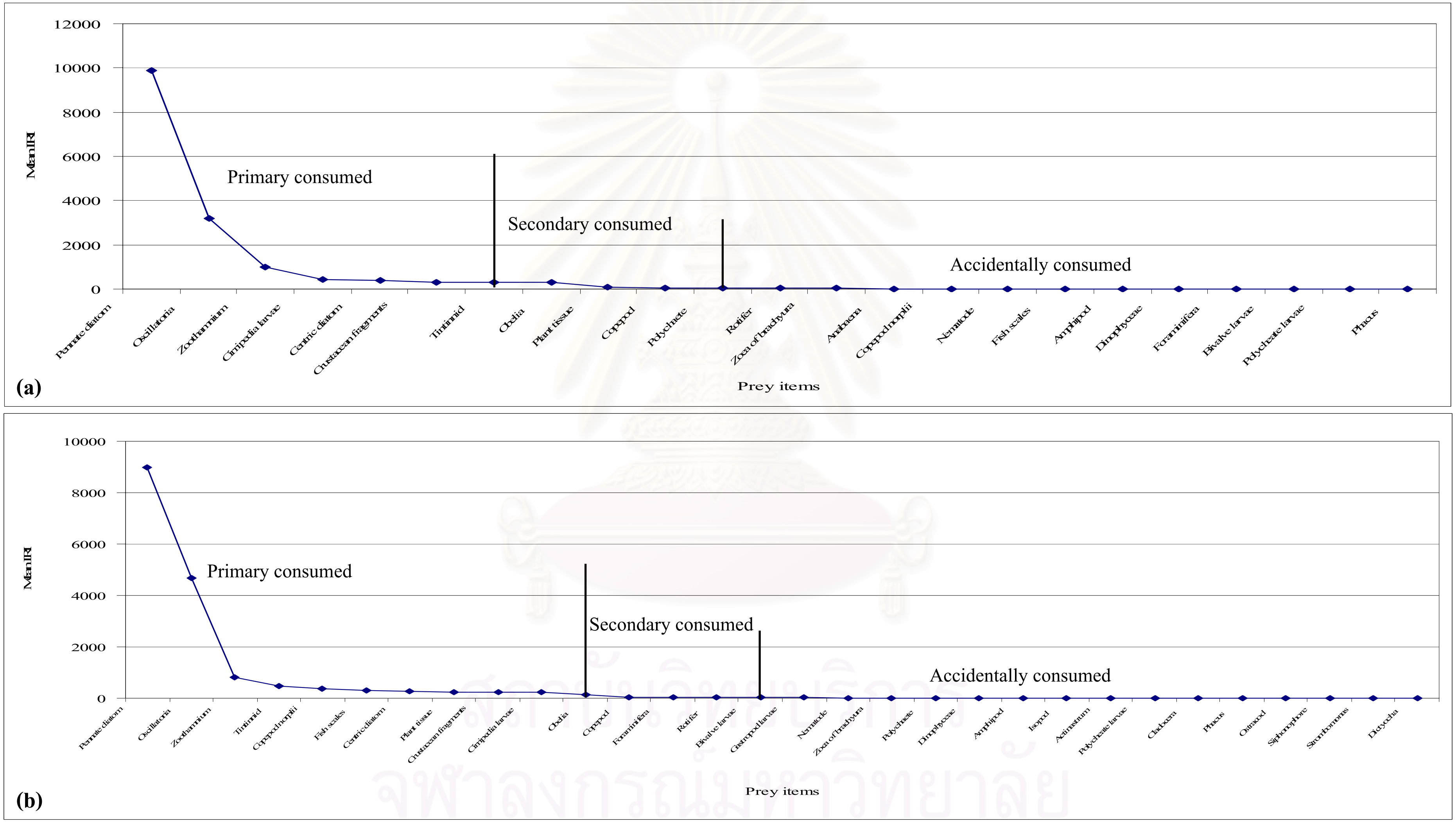



Figure 3.13 Diet preferences of spotted scat larvae in mangrove forests during low salinity (a) and high salinity (b)

Table 3.4 List of prey items identified in juvenile spotted scat stomachs at different salinity from mangrove forests and index of relative importance (IRI) value (C*n* = percentage numerical abundance, C*v* = percentage volumetric composition, *F* = percentage frequency of occurrence)

| Prey items | Low salinity : Mangrove forests | | | | High salinity : Mangrove forests | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Cn*** | ***Cv*** | ***F*** | **IRI** | ***Cn*** | ***Cv*** | ***F*** | **IRI** |
| *Anabaena* | - | - | - | - | 0.562 | 0.007 | 15.000 | 8.523 |
| *Merismopedia* | 0.005 | 0.000 | 1.111 | 0.006 | 0.219 | 0.000 | 7.778 | 1.705 |
| *Oscillatoria* | 28.676 | 9.238 | 100.000 | 3791.435 | 24.939 | 9.024 | 98.333 | 3339.695 |
| *Senedesmus* | 0.000 | 0.000 | 2.222 | 0.001 | - | - | - | - |
| *Spirogyra* | - | - | - | - | 0.320 | 0.001 | 11.667 | 3.742 |
| *Trachelomonas* | - | - | - | - | 0.000 | 0.000 | 1.667 | 0.000 |
| Centric diatoms | 0.819 | 0.210 | 93.333 | 96.021 | 0.779 | 0.155 | 93.889 | 87.708 |
| Pennate diatoms | 57.533 | 38.793 | 98.889 | 9525.576 | 61.869 | 49.975 | 100.000 | 11184.413 |
| Dinophyceae | 0.034 | 0.018 | 26.667 | 1.381 | 0.036 | 0.017 | 28.333 | 1.511 |
| Tintinnids | 0.918 | 0.448 | 97.778 | 133.564 | 0.546 | 0.356 | 90.556 | 81.645 |
| Foraminiferans | 0.017 | 0.100 | 42.222 | 4.912 | 0.005 | 0.060 | 32.778 | 2.129 |
| *Zoothamnium* | 3.710 | 4.668 | 87.778 | 735.414 | 6.003 | 4.746 | 75.556 | 812.160 |
| *Obelia* | 0.935 | 16.031 | 44.444 | 754.031 | 0.935 | 16.068 | 49.444 | 840.722 |
| Medusae | 0.000 | 0.000 | 1.111 | 0.000 | 0.000 | 0.000 | 1.111 | 0.000 |
| Rotifer | 0.039 | 0.034 | 52.222 | 3.830 | 0.084 | 0.040 | 61.667 | 7.652 |
| Ostracod | 0.001 | 0.002 | 5.556 | 0.021 | 0.002 | 0.003 | 11.111 | 0.049 |

Table 3.4 (Continued)

| Prey items | Low salinity : Mangrove forests | | | | High salinity : Mangrove forests | | | |
|---|---|---|---|---|---|---|---|---|
| | ***Cn*** | ***Cv*** | ***F*** | **IRI** | ***Cn*** | ***Cv*** | ***F*** | **IRI** |
| Cirripedia larvae | 0.018 | 0.110 | 27.778 | 3.566 | 0.017 | 0.106 | 27.222 | 3.361 |
| Copepod norplii | 0.023 | 0.115 | 30.000 | 4.138 | 0.024 | 0.103 | 37.222 | 4.712 |
| Copepod | 0.260 | 3.036 | 71.111 | 234.377 | 0.228 | 2.436 | 75.556 | 201.292 |
| Lucifer | 0.000 | 0.005 | 3.333 | 0.019 | - | - | - | - |
| Mysidacea | 0.003 | 0.126 | 7.778 | 1.001 | 0.003 | 0.120 | 12.222 | 1.501 |
| Zoea of brachyura | 0.002 | 0.100 | 10.000 | 1.020 | 0.002 | 0.082 | 8.889 | 0.746 |
| Nematode | 0.214 | 0.352 | 92.222 | 52.186 | 0.184 | 0.295 | 90.000 | 43.063 |
| Polychaete larvae | 0.108 | 1.331 | 25.556 | 36.760 | 0.004 | 0.053 | 5.000 | 0.286 |
| Polychaete | - | - | - | - | 0.103 | 1.284 | 20.000 | 27.739 |
| Gastropod larvae | 0.006 | 0.366 | 12.222 | 4.551 | 0.006 | 0.360 | 12.222 | 4.470 |
| Bivalve larvae | 0.007 | 0.192 | 14.444 | 2.864 | 0.007 | 0.192 | 14.444 | 2.864 |
| Amphipod | 0.010 | 0.982 | 21.111 | 20.950 | 0.008 | 0.539 | 14.444 | 7.903 |
| Isopod | 0.000 | 0.025 | 2.222 | 0.057 | 0.000 | 0.024 | 1.111 | 0.027 |
| Insects | 0.007 | 0.051 | 11.111 | 0.647 | 0.001 | 0.014 | 5.556 | 0.083 |
| Plant tissue | 4.729 | 8.824 | 81.111 | 1099.341 | 1.484 | 4.157 | 83.333 | 470.089 |
| Crustacean fragments | 0.363 | 3.055 | 73.333 | 250.639 | 0.128 | 3.545 | 72.222 | 265.277 |
| Fish scales | 1.562 | 11.787 | 78.889 | 1053.066 | 1.501 | 6.240 | 78.889 | 610.684 |

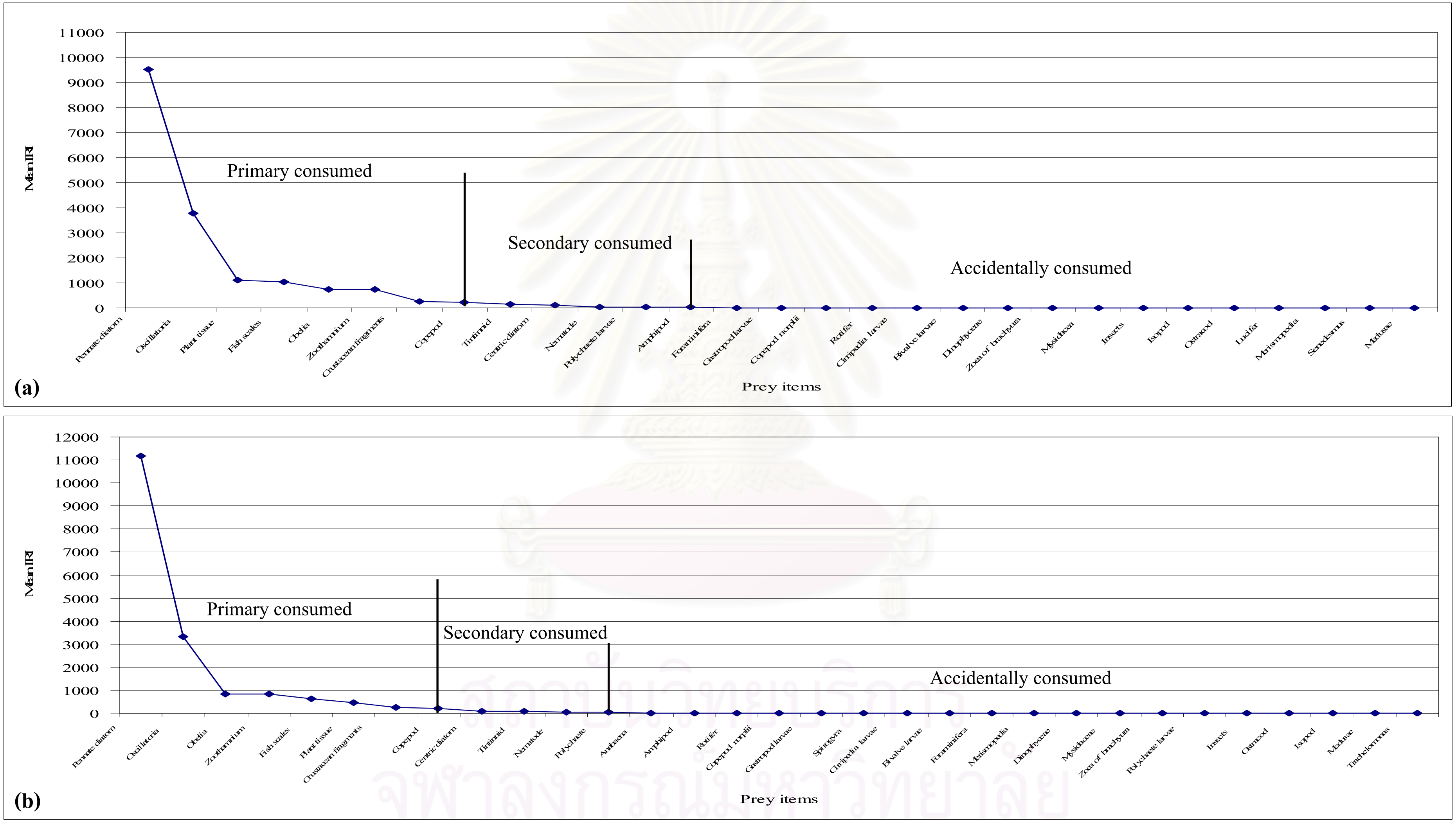



Figure 3.14 Diet preferences of juvenile spotted scat in mangrove forests during low salinity (a) and high salinity (b)

Prey items were consumed by spotted scat all stages more diverse in high salinity period than low salinity period correlated with high density of microphytoplankton, zooplankton and detritus in these area. The average density of microphytoplankton ranged from $1.28x10^{3}$ to $3.45x10^{4}$ cells/l in high salinity and from $6.51x10^{3}$ to $1.59x10^{5}$ cells/l in low salinity period. Zooplankton community was dominated by arthropod crustaceans in particular copepods which contributed more than 60% of the total zooplankton density. The second most abundance zooplankton was crustacean larvae consisted of brachyuran larvae, larvae of shrimps and barnacle larvae. Mysid, lucifers, sergestids, rotifers, bivalve larvae, gastropod larvae and larvaceans were also common in the area. While organic detritus in form of underground, pneumatophore and seedling biomass in the mangrove plantations of Pak Phanang Estuary was on the average of 443.06 $g/m^{2}$ during study period. Protozoan and benthos of three stages in mangrove forests showed significant difference ($p<0.05$). Beside the microphytoplankton were primary consumed in spotted scat larvae, they also select protozoa and zooplankton consumed meanwhile Arthropoda, insects, and detritus increased in juvenile stage. Adults found benthos and detritus in stomach increasing.

From the results showed nich shift in prey items from microphytoplankton which were dominant prey items in larvae. They have 83.18% meanwhile juveniles have 78.27% and found 71.23% in adults. Protozoan found the highest number in larvae were 7.84%, whereas the juveniles and adults found 4.94% and 3.71% respectively. The benthos and detritus have increased density from larvae to adults. The detritus were found 3.61% in larvae, juveniles 10.46% and 18.31% in adults (Figure 3.20). Prey items in each stage of spotted scat showed ontogenietic diet change.

Table 3.5 List of prey items identified in adult spotted scat stomachs at different salinity from mangrove forests and estuarine waterways and index of relative importance (IRI) value (C*n* = percentage numerical abundance, C*v* = percentage volumetric composition, *F* = percentage frequency of occurrence)

| Prey items | Low salinity : Mangrove forests | | | | High salinity : Mangrove forests | | | | Low salinity : Estuarine waterways | | | | High salinity : Estuarine waterways | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI |
| *Anabaena* | 9.278 | 0.901 | 56.667 | 576.857 | - | - | - | - | - | - | - | - | - | - | - | - |
| *Merismopedia* | 7.617 | 0.004 | 3.333 | 25.404 | - | - | - | - | - | - | - | - | - | - | - | - |
| *Oscillatoria* | 17.049 | 1.253 | 93.333 | 1708.262 | 27.735 | 8.506 | 100.000 | 3624.070 | 0.127 | 0.009 | 80.000 | 10.836 | 21.714 | 5.027 | 100.000 | 2674.151 |
| *Spirulina* | 1.508 | 0.004 | 13.333 | 20.170 | - | - | - | - | - | - | - | - | - | - | - | - |
| *Spirogyla* | 0.008 | 0.247 | 16.667 | 4.248 | - | - | - | - | - | - | - | - | - | - | - | - |
| Centric diatoms | 0.178 | 0.041 | 43.333 | 9.513 | 0.679 | 0.450 | 100.000 | 112.942 | 0.022 | 0.004 | 50.000 | 1.288 | 7.081 | 3.562 | 75.000 | 1064.259 |
| Pennate diatoms | 61.500 | 44.507 | 100.000 | 10600.641 | 61.025 | 20.242 | 100.000 | 8126.715 | 0.132 | 0.780 | 80.000 | 72.945 | 46.752 | 23.452 | 100.000 | 7020.464 |
| Tintinnids | 0.012 | 0.041 | 46.667 | 2.493 | 0.533 | 1.977 | 100.000 | 250.978 | 0.093 | 0.040 | 60.000 | 8.001 | 1.078 | 0.522 | 82.500 | 159.919 |
| Foraminiferans | 0.009 | 0.048 | 23.333 | 1.323 | 0.007 | 0.185 | 50.000 | 9.581 | 0.035 | 0.188 | 50.000 | 11.163 | 0.268 | 1.103 | 57.500 | 137.072 |
| *Zoothamnium* | 1.280 | 10.516 | 53.333 | 629.145 | 0.830 | 3.598 | 90.000 | 398.534 | 96.779 | 97.916 | 60.000 | 11681.720 | 15.214 | 18.759 | 35.000 | 3397.301 |
| Rotifer | 0.030 | 0.046 | 10.000 | 0.761 | 0.003 | 0.092 | 20.000 | 1.896 | - | - | - | - | 0.038 | 0.097 | 22.500 | 13.553 |
| Ostracod | 0.080 | 0.129 | 16.667 | 3.482 | - | - | - | - | 0.001 | 0.000 | 10.000 | 0.010 | 0.027 | 0.008 | 17.500 | 3.530 |
| Cirripedia larvae | 0.007 | 0.019 | 3.333 | 0.085 | 0.008 | 0.354 | 60.000 | 21.711 | - | - | - | - | 0.026 | 0.046 | 15.000 | 7.149 |
| Copepod nauplii | 0.051 | 1.153 | 36.667 | 44.125 | 0.004 | 0.078 | 30.000 | 2.440 | - | - | - | - | 0.040 | 0.306 | 37.500 | 34.617 |

Table 3.5 (Continued)

| Prey items | Low salinity : Mangrove forests | | | | High salinity : Mangrove forests | | | | Low salinity : Estuarine waterways | | | | High salinity : Estuarine waterways | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI |
| Copepod | 0.119 | 19.460 | 60.000 | 1174.706 | 0.033 | 3.389 | 70.000 | 239.572 | 0.007 | 0.086 | 60.000 | 5.562 | 0.210 | 3.257 | 75.000 | 346.711 |
| Mysidacea | 0.078 | 3.522 | 20.000 | 72.008 | - | - | - | - | - | - | - | - | 0.009 | 0.125 | 12.500 | 13.396 |
| Zoea of brachyura | 0.001 | 0.001 | 3.333 | 0.005 | 0.002 | 0.109 | 10.000 | 1.108 | - | - | - | - | - | - | - | - |
| Fish egg | - | - | - | - | - | - | - | - | - | - | - | - | 0.001 | 0.011 | 2.500 | 1.241 |
| Nematode | 0.076 | 3.232 | 76.667 | 253.548 | 0.259 | 2.602 | 100.000 | 286.050 | 0.003 | 0.001 | 30.000 | 0.115 | 0.580 | 2.853 | 82.500 | 343.284 |
| Polychaete larvae | - | - | - | - | 0.003 | 0.079 | 20.000 | 1.640 | - | - | - | - | 2.152 | 9.965 | 47.500 | 1211.703 |
| Gastropod | 0.003 | 0.074 | 6.667 | 0.513 | 0.001 | 0.058 | 10.000 | 0.581 | - | - | - | - | 0.001 | 0.020 | 5.000 | 2.097 |
| Onchidium egg | - | - | - | - | 0.149 | 0.311 | 20.000 | 9.209 | 2.751 | 0.460 | 20.000 | 64.205 | 0.614 | 2.266 | 7.500 | 287.969 |
| Bivalve | 0.007 | 0.251 | 6.667 | 1.725 | 0.020 | 0.115 | 20.000 | 2.701 | 0.001 | 0.015 | 10.000 | 0.156 | 0.061 | 0.349 | 20.000 | 41.064 |
| Amphipod | 0.009 | 1.208 | 13.333 | 16.231 | 0.036 | 3.012 | 70.000 | 213.324 | 0.001 | 0.094 | 20.000 | 1.913 | 0.412 | 8.007 | 40.000 | 841.830 |
| Taniadacean | - | - | - | - | 0.004 | 0.026 | 10.000 | 0.298 | - | - | - | - | 0.003 | 0.015 | 2.500 | 1.752 |
| Insects | - | - | - | - | 0.001 | 0.007 | 10.000 | 0.071 | - | - | - | - | - | - | - | - |
| Plant tissue | 0.202 | 1.177 | 46.667 | 64.340 | 6.774 | 35.921 | 90.000 | 3842.562 | 0.008 | 0.011 | 40.000 | 0.772 | 1.660 | 0.903 | 40.000 | 256.365 |
| Crustacean fragments | 0.799 | 10.880 | 76.667 | 895.426 | 0.981 | 5.629 | 100.000 | 661.025 | 0.025 | 0.176 | 60.000 | 12.064 | 1.961 | 6.036 | 77.500 | 799.720 |
| Fish scale | 0.100 | 1.284 | 46.667 | 64.566 | 0.915 | 13.262 | 60.000 | 850.573 | 0.004 | 0.104 | 30.000 | 3.246 | 0.098 | 13.310 | 22.500 | 1340.793 |

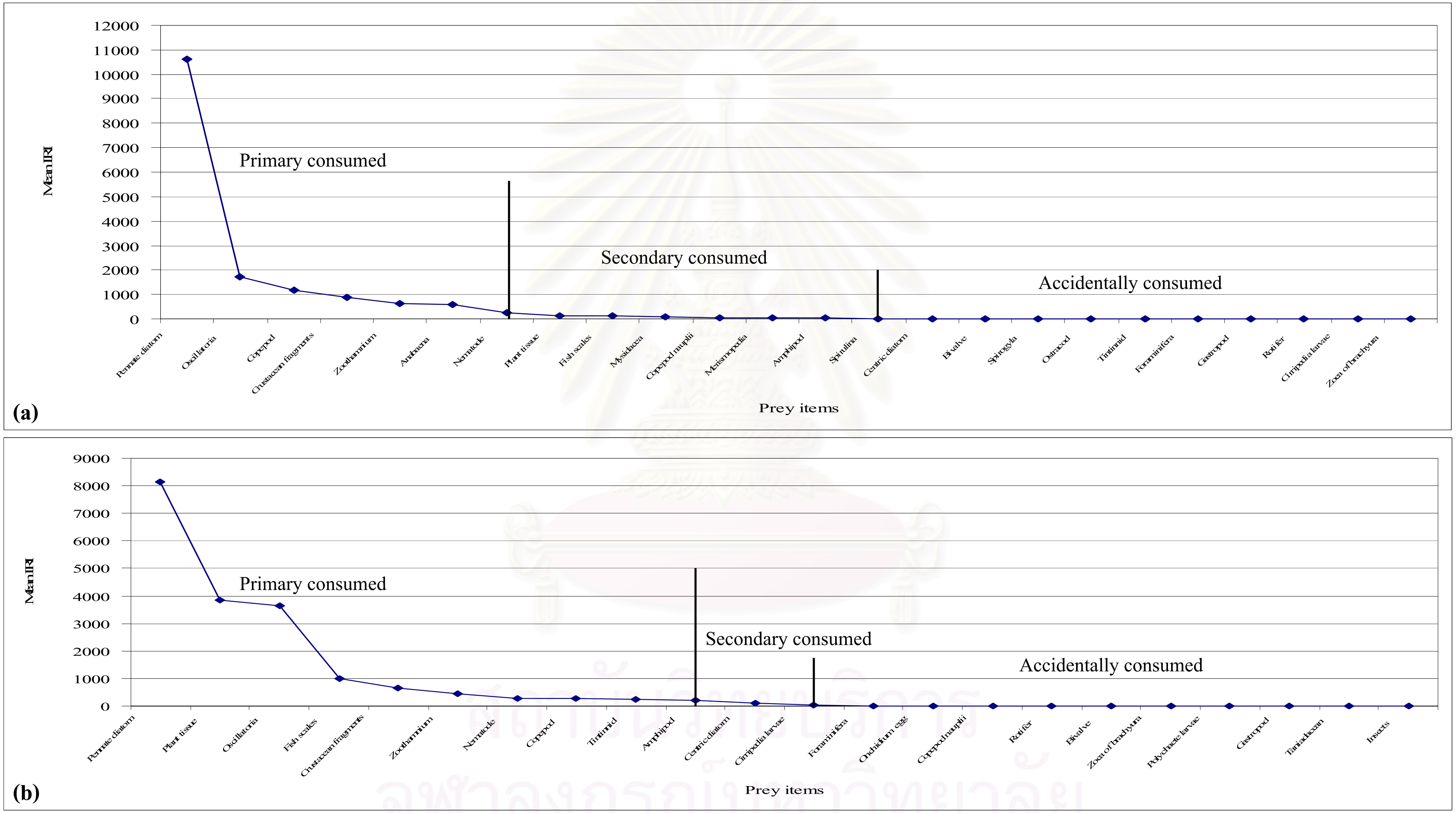



Figure 3.15 Diet preferences of adult spotted scat in mangrove forests during low salinity (a) and high salinity (b)

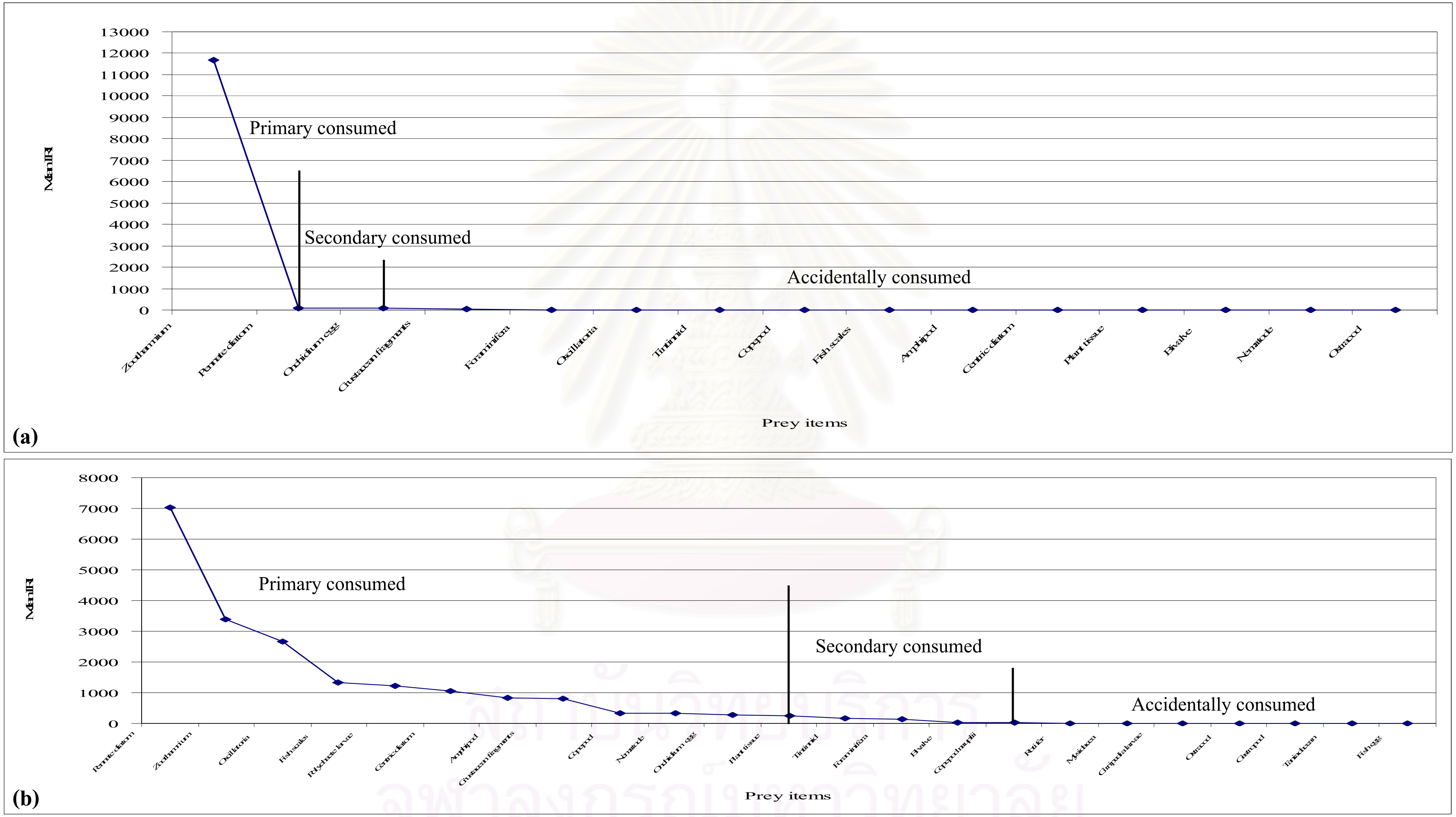



Figure 3.16 Diet preferences of adult spotted scat in estuarine waterways during low salinity (a) and high salinity (b)

2.3 Food quality

Organic matter in stomach content of spotted scat in three stages was analyzed for CHN content to determind the sources deriving from organic matter living organism or non living organism. Living organisms have the organic carbon and organic nitrogen ratio lower than those from non living organism.

The results showed organic carbon higher than organic nitrogen. The average carbon value (n=5, Mean±SE) of larvae, juveniles and adults were 13.270±1.661, 23.976±1.456 and 22.875±2.093, respectively. The average nitrogen value (n=5, Mean±SE) of larvae, juveniles and adults were 2.788±0.351, 5.361±0.379 and 4.393±0.497 (Figure 3.17).

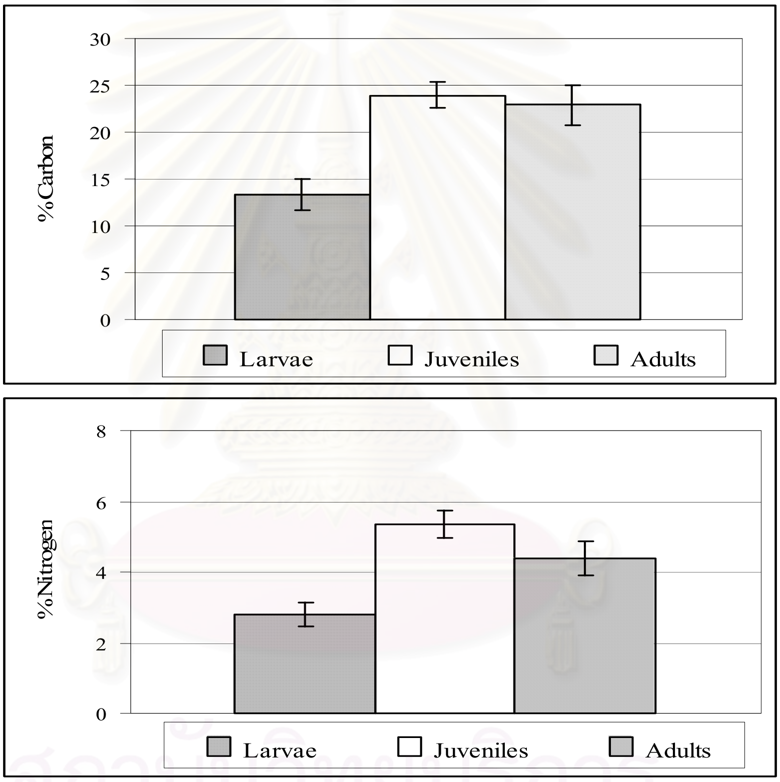



Figure 3.17 Carbon and nitrogen (Mean±SE) from stomach content of spotted scat

The average C:N ratio of spotted scat larvae was 4.8:1, 4.5:1 of juveniles and adults as 5.2:1(Figure 3.18). The C:N ratio on three stages of spotted scat not showed significant difference ($p$>0.05). However, detritus density has increased from the larvae to adult diets. Detritus were found 3.61% in larvae, juvenile 10.46% and 18.31% in adults. The results also confirmed spotted scat feed on microphytoplankton and mangrove detritus due to this results correlated Kato *et al.* (2007) that reported spotted scat of omnivore have lower nitrogen value because omnivore takes both plants and animals. Detital aggregate appears relatively rich in energy yielding substrates, but deficient in digestible protein (Bowen *et al.*, 1995). In omnivorous diet like that of fathead minnows, Pimephales promelas, protein gained from difficult to obtain prey can be supplemented with energy from abundant detrital aggregate to provide the nutritional balance needed for rapid growth. In addition, C:N ratio of algae and phytoplankton were 5-15:1 (Duarte, 1992) and mangrove detritus 4.2-8.5:1 (Russell-Hunter, 1970). Microphytoplankton and mangrove detritus were found in the diet showed maximize energy gain per unit time of spotted scat due to high density of microphytoorganic and detritus among prey items. Moreover the results correlated with high organic detritus in term of forest biomass in mangrove plantations.

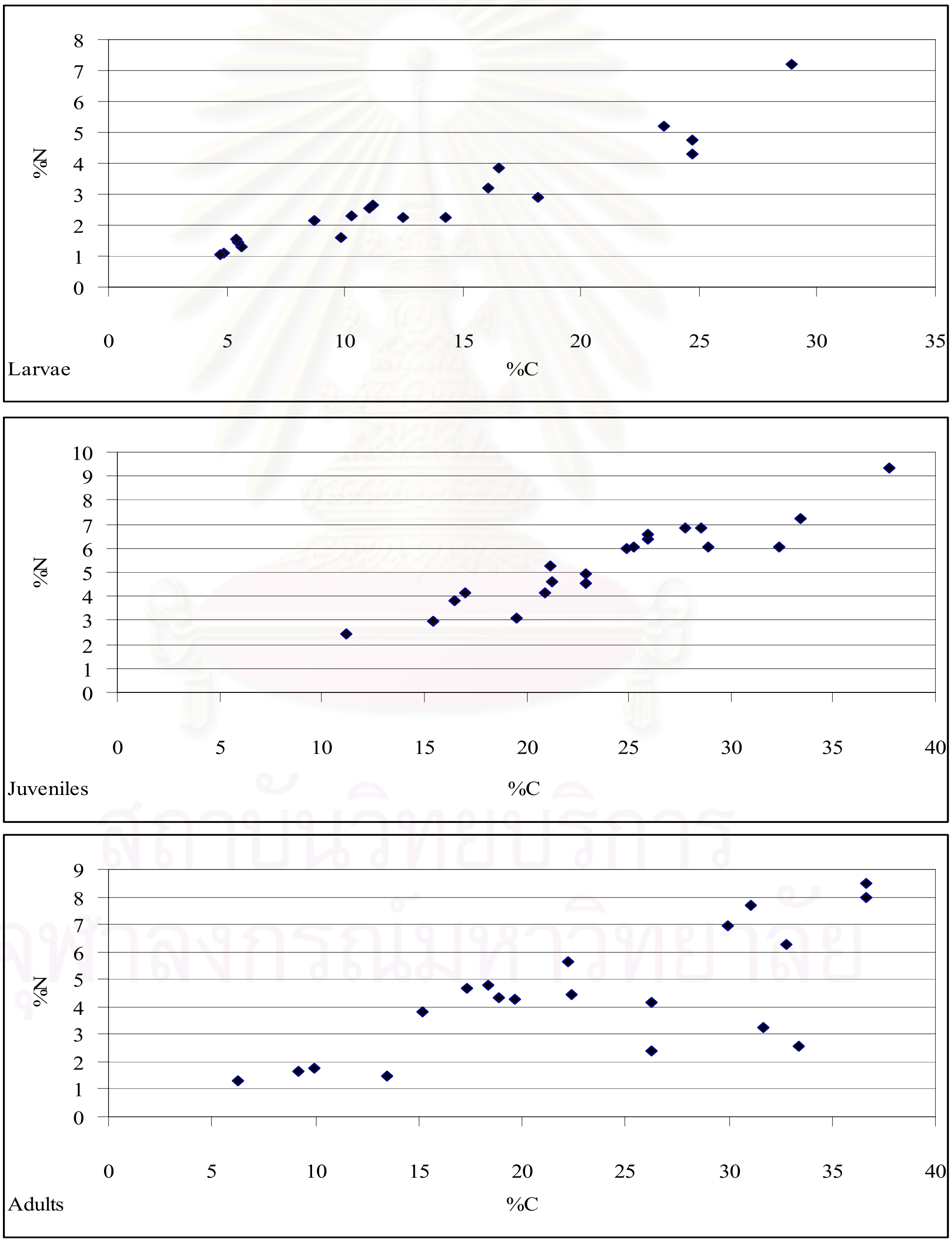



Figure 3.18 Carbon and nitrogen ratio from stomach content in three stages of spotted scat

### 3. Feeding Behavior and Preference as Related to Morphological Adaptation

#### 3.1 Feeding behavior

From feeding preference experiment, spotted scat showed five stages of feeding behavior (Figure 3.19): 1. orientation and encountering prey (search time), 2. position and pursuit, 3. attack including approach and capture, 4. ingestion and 5. digestive pause before engaging in another bout of feeding. The last four feeding behavior collectively resulted in handling time. The importance of searching the foraging cycle depends on the relative size and activitiy of predator and prey (O'Brien *et al*., 1990). Pursuit of the prey, its capture, ingestion and a digestive pause could possibly consume a considerable period of time (Gerking, 1994). The sequence of behaviors a predator migh be expected to slow, together with factors potentially influencing them (Endler, 1991). There are two types of factor. Factores internal to the fish include its morphology, its capacity to learn and its current physiological state. External factors deriving from the prey are all those feature that the prey has evolved to avoid and evade cpture. Optimal foraging theory has concentrated on limited aspects of the cycle, for example, whether or not to incude a particular prey type in the diet, and the behavioural tactics the forager should use to achieve the strategy that maximizes fitness.

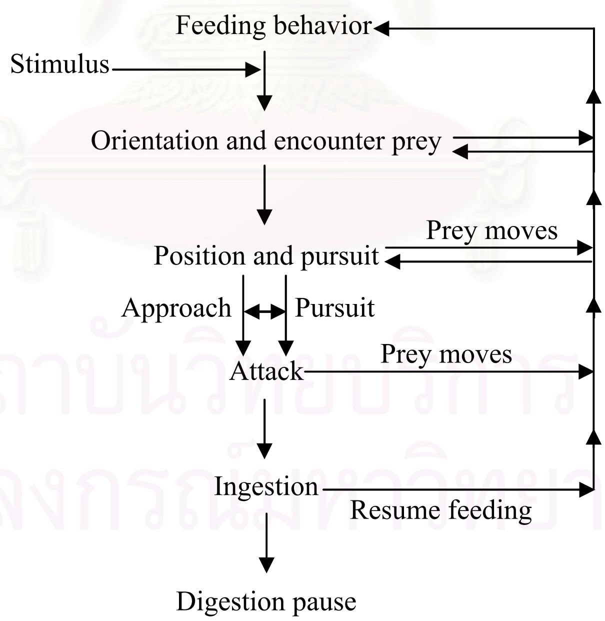



Figure 3.19 Flow chart of behavior types in feeding of spotted scat, *Scatophagus argus* (modified from Gehrke, 1988)

**Larval feeding behavior**

Feeding behavior of larvae was observed when fed with microphytoplankton, *Chaetoceros* sp. and *Skeletonema* sp. The basal activity pattern presented below as in Table 3.6.

Table 3.6 Feeding behavior of spotted scat larvae

| Feeding behavior of larvae | |
|---|---|
| **Feeding behavior stages** | **Feeding behavior in experiment** |
| 1. Orientation and encounter the prey (search time) | After provide *Chaetoceros* sp. and *Skeletonema* sp., at 7 second spotted scat larvae began searching the prey near bottom area. Larvae moved to left side and turn back to right side, moved up and down in water column and moved to aside for feeding. Average handing time for searching total 50 second. Fish larvae were stimulus by prey density. Fish used both olfactory and gustatory sense can detect and locate food source. |
| 2. Positioning and pursuit | Fish dived to bottom for feeding at 57 seconds after provided food. |
| 3. Attack and capture | The lip scraped prey items off surface bottom and bent the body into S-shape. Then larvae fed aside the case by their lips and teeth to the substrate, swam up and down and bent the body from a straight line into an S-shape quickly achieving an opposite S and propagating S-waves along the body. Average handing time for searching total 36 second. |
| 4. ingestion | The fish opened its mouth to filter food items and ingested at the mid water. |
| 5. Digestive pause before engaging in another bout of feeding | After capture and ingestion, larvae slow swam and moved to surface and disperse no direction around the pond and raised the lip to feed. Average total time 1.30 minust before engaging in another bouth of feeding. Frequency of feeding showed decreasing follow density of food and handing time increasing. |

Feeding behavior of fish larvae including orientation and position to capture changed from random to direted movement involved processes of stimulus detection and source location. Chemical stimuli may be a factor location of prey by larval fish. For example, norther ancohovy appear to locate dense patches of *Gymnodinum* prior to eye pigmentation (Hunter and Thomas, 1974). The predatory responses of early larval fish are triggered by objects up to a maximum size of 1 $mm^2$, but the best information to date concerning orientation by fish to optimal stimulus size (Hyatt, 1979). An optimal stimulus size to elicit approach by fish, the lower size limit of discovery and attraction to prey may often be determined by the visual acuity of predators while the upper size limit is more likely related to the positive identification of an object as potential food. It is most likely that differences between fish species are innate and that they are directly related to other characteristics of the predators, such as their capacity to capture and ingest prey of particular sizes.

**Juvenile feeding behavior**

Table 3.7 showed feeding behavior of juveniles observed from feeding preference experiments.

Table 3.7 Feeding behavior of juvenile spotted scat

| Feeding behavior of juveniles | |
|---|---|
| **Feeding behavior stages** | **Feeding behavior in experiment** |
| 1. Orientation and encounter the prey (search time) | After provide *Chaetoceros* sp., *Skeletonema* sp. and rotifers, juvenile swam toward a prey when located above, below, or parallel to their position in the water. Time beginning for search at 2 second. |
| 2. Positioning and pursuit | Juvenile began feeding at 6 seconds after provided food. Most fish swam near bottom. |
| 3. Attack and capture | Juveniles slant body lie parallel to the bottom, lip scraped prey items off surface bottom and rotated to circle. The lip scraped prey off surface bottom for long time from 1.41-1.53 minute. During fed, fish will slant body from left to right or opposite by using 2 seconds in timess and sometime rotate to circle. While feeding the body bent into S-shape striking at high acceleration. Fish cruised at two to three body lengths per second for long period of time but because the time spent in attack is very short, it is more likely that burst speeds will influence attack success. Burst speeds do appear to be related to the acquisition of particular classes of foods by predator fish. Juvenile move to within striking range and then snaps at the prey from an S-shaped position of the trunk of the body which a lash of the tail forces toward its quarry. Some fish used lip scrape food at aside the case and bottom while feeding the body bent into S-shape striking at high acceleration. Average handing time to capture total 3 minutes/time. |
| 4. Ingestion | The fish open its mouth during swim food may also be ingested by skimming along the bottom with the lips in contact with the surface bottom. The actual act of ingestion occurs when fish extends its head and opens its mouth, budge mouth to chew food. Total time for ingestion total 2 minutes/time. |
| 5. Digestive pause before engaging in another bout of feeding | The steps of feeding behavior were repeated during experiments. They swam undiret around the pond, skim along the bottom and aside with open mouth. |

**Adult feeding behavior**

Feeding behavior of adults was showed in Table 3.8 with the serial of 5 stages.

Table 3.8 Feeding behavior of adult spotted scat

| **Feeding behavior of adults** | |
|---|---|
| **Feeding behavior stages** | **Feeding behavior in experiment** |
| 1. Orientation and encounter the prey (search time) | After provide *Chaetoceros* sp., *Skeletonema* sp. and rotifers, adult swam searched food at the mid water and near bottom. Time beginning for search at 12 second. |
| 2. Positioning and pursuit | Adult began feeding at 50 seconds after provided food. Most fish swam near bottom. |
| 3. Attack and capture | Adult fish fed on the bottom and aside the case. Fish slanted body not dive to the bottom, lip scraped prey items off surface bottom while feeding the body bent into S-shape striking at high acceleration. When lip touched the bottom its lift the mouth and switch behavior through the time. Thence fed on the bottom by used lip scrape prey items off surface bottom no direction and slant body for time 18 seconds while feeding the body roll from side to side about 2-3 seconds/times sometime rotate to circle. Sometime fish fed aside the case higher by scrape the lip up and down the case. Average handing time to capture total 2 minutes/time. |
| 4. Ingestion | Fish swam slowly during swim will open mouth and budge mouth to chew food. Total time for ingestion total 15 seconds/time. |
| 5. Digestive pause before engaging in another bout of feeding | The steps of feeding behavior were repeated during experiments. They swam undiret around the pond, skim along the bottom and aside with open mouth. Some fish moved to the surface during move will open mouth touch surface 2 seconds and then swam turn back mid water to 3-4 seconds. |

Searching time of juvenile has slightly rapid than larvae and adults, time beginning at 2 second. Moreover positioning and pursuit time of juveniles began rapid than adult and larvae respectively. Attack and capture preys of each stage have the same pattern. Fish body bent into S-shape striking at high acceleration to capture prey. Mostly fish scraped prey items off surface bottom. Ingestion happened during swimming with open mouth and budge mouth to chew prey item. The steps of feeding behavior were repeated during experiments.

The detection and the process of identification were dependent on specific stimulus features of food objects (e.g. movement, size, shape). Fish sighted the prey making adjustments in position as the prey moves. Thus vision is an important sense, influencing feeding ability. Changes in the complexity of the eye during development lead to increased visual performance as measured by reactive distance (Blaxter and Staines, 1971), visual acuity (Rahmann *et al*., 1979; Neave, 1984) and sensitivity to light (Blaxter, 1986). Every sensory system is adapted to respond to certain kinds of stimuli, thus differential exploitation of foods by fish will often be an outcome of the process of sensory discrimination, that is, fish will selectively exploit some food items if they react differently to emitted stimuli. Once a food item has been detected and identified, its specific features determine the subsequent motor responses of the predator, which can either be to approach, ignore, or actively avoid a particular object. The incidence of predation is affected by both fish size and prey size. The size of prey influences the probability of detection, by increasing the distance at which fish respond. For any predator that uses vision in the search for prey, there will be an upper and lower limit on the sizes of prey the predator will detect or if detected, respond to positively (Ewert, 1974).

### 3.2 Feeding preference

#### Larval feeding preference

Fish larvae foraged primarily on *Chaetoceros* sp. that fall within a preferred size range (6-24 μm) governed by the mouth size (1.2 mm) (Table 3.9). First feeding in most marine fish larvae is usually on organisms < 100 μm in width, which tend to be 1-3% of larval length. The prey consumed by fish larvae broaden as larval size increases. Feeding behavior of spotted scat larvae showed patteren corresponded to Holling’s Functional Response in Type 3. Larval feeding showed sigmoid exploitation feeding curve with an increase in consumption, over a threshold density.

#### Juvenile feeding preference

Juvenile spotted scat preferred *Chaetoceros* sp., *Skeletonema* sp. and rotifer respectively (Table 3.9). *Chaetoceros* sp. in preference experiments was first selected due to their density (3,845 cells/ml) than rotifer (7 individuals/ml). Therefore, the availability of the prey to predators depend not only its population density, but also its activity, exposure and defence mechanisms (Moitoza and Phillips, 1979; Vinyard, 1980). Juveniles selected their food according to the optimal prey size and high density prey similared to spotted scat larvae. Feeding behavior of juveniles showed patteren corresponded to Holling’s Functional Response in Type 3. They focused most of their attention on more abundant foods, switching to less common food only when it exceeds some threshold density. Moreover they required some learning to exploit food at a maximum rate. At low food densities they do not have sufficient exposure to a particular food item to fully develop their searching and handling skills.

**Adutl feeding preference**

Adult spotted scat selected *Skeletonema* sp., *Chaetoceros* sp. and rotifer respectively. *Skeletonema* sp. was selected due to the chain-like morphology that easily encounter and catch. Furthermore, the densities of *Skeletonema* sp. was hightest as compared to other prey items. Densities of *Skeletonema* sp. were 6,460 cells/ml meanwhile *Chaetoceros* sp. 1,954 cells/ml and rotifer 4 individuals/ml. The diet selection depends on the density of the more profitable items (Table 3.9). Adult spotted scat feeding behavior corresponded to Holling's Functional Response in Type 1. The consumption increased linearly as food density increases and then levels off abruptly at some maximum feeding rate which the consumption did not increase. Type 1 functional responses are consumers that require little or no time to process their food.

Table 3.9 Feeding preference on microphytoplankton and zooplankton of spotted scat

| **Manly's alpha index** | **Larvae** | | **Juveniles** | | **Adults** | |
|---|---|---|---|---|---|---|
| Food types | Replication 1 | Replication 2 | Replication 1 | Replication 2 | Replication 1 | Replication 2 |
| α *Chaetoceros* sp. | 0.852 | 0.924 | 0.576 | 0.593 | 0.324 | 0.222 |
| α *Skeletonema* sp. | 0.148 | 0.076 | 0.248 | 0.283 | 0.561 | 0.665 |
| α Rotifer | - | - | 0.177 | 0.124 | 0.115 | 0.112 |

**4. Ontogenetic Niche Shift in Spotted Scat**

Spotted scat showed niche shift in relation to the change in food selection. The shift in food preference in spotted scat occurred due to ontogenetic changes and acquiring the ability to catch highly prey items with growth. Ontogenetic differences in feeding habits have resulted form including increases mouth gape size, changing numbers of gill rakes, jaw teeth and development of the digestive system. At beginning of feeding, spotted scat developed mouth gape from 0.12 cm in larvae to 0.61 cm in adults that they could feed on microphytoplankton to large size in benthos such as polychaete, tanaidacean. Rows of teeth increased from 1-2 rows of the upper and lower jaw in larvae to 6-7 rows in adults. Ciliiform teeth were also found beginning juveniles. Therefore, they have increased the ability to catch and chew the prey. Gill raker varied in number from 13-20 increasing the ability to filter and collect prey items. The enlarge stomach in large fish showed the large comsumption volume of food to digest. In addition, the ratio of intestine length/standard length increased from larvae to adult of 0.59-4.29 showed increasing high digestion and assimilation. Therefore, the variations in the component of prey items including microphytoplankton, protozoan, zooplankton, benthos and detritus were to the related feeding morphology structure in each stage.

Microphytoplankton was dominant prey items in larvae of approximate 83.18%. Microphytoplankton in juvenile diets was 78.27% and 71.23% in adults. Protozoan found in larval diet of 7.84%, whereas the juveniles and adults of 4.94% and 3.71% respectively. Benthos and detritus density have increased from larvae to adults diets. Detritus were found 3.61% in larvae, juveniles 10.46% and 18.31% in adults (Figure 3.19). Prey size related to the changes in feeding morphological structure correlated to several studies such as Thong and Sasekumar (1984) reported *Leiognathus splendens* in size 2.9-3.0 cm eaten copepod and cirripede norplius whereas 7.5 cm ate mollusc. Okach and dadzie (1988) studied adult *Bagrus docmac* in the Nyanza Gulf of Lake Victoria feeded mostly on fish. Juveniles prefer aquatic benthic invertebrates dominating. Sritakon *et al*. (2001) studied stomach content of sand whiting (*Sillago sihama* Forsskål, 1775) found the main diets of sand whiting are arthropods (crustaceans) and annelids (polychaetes). Stomach content of sand whiting changed with its size. Small fish in size $\leq$ 8.0 cm TL consumed crustaceans mainly copepods, amphipods and decapods meanwhile larger fish $\geq$ 8.1 cm TL fed on polychaetes. A morphological examination of the feeding apparatus suggested that the size of important prey items consumed was determined by gape height and jaw width. Prey available to different size classes of fish was determined by combining information on microhabitat use, foraging behaviors, and prey volumes in the substratum.

Figure 3.20 displayed the ontogenetic niche shift in spotted scat. In larval stage, spotted scat predominantly fed on water column taking microphytoplankton. Juveniles were transition stages from fed on water column to substrata taking resuspended benthic diatoms, zooplankton especially meroplankton rather than holoplankton, benthos and detritus. Adults feed on substrata taking the whole prey items, including the benthic diatoms, benthos and detritus.

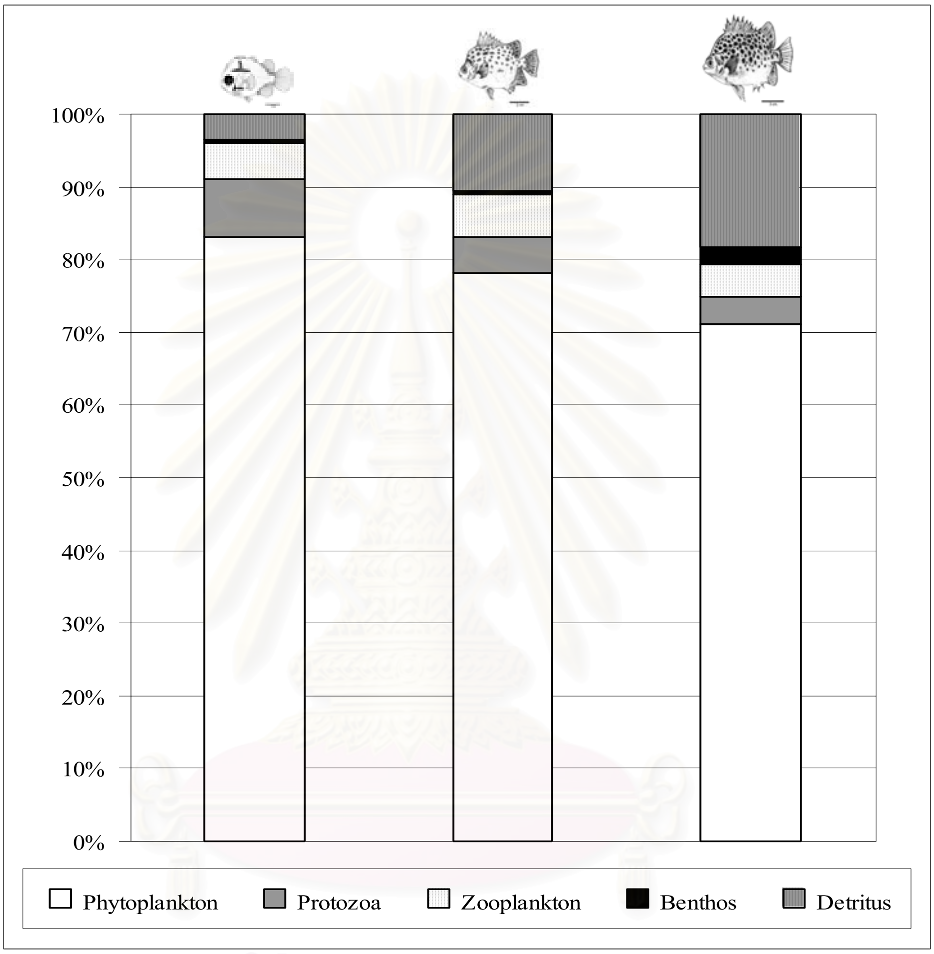



Figure 3.20 Ontogenetic niche shift in spotted scat in mangrove forests at Pak Phanang Estuary, Nakhon Si Thammarat Province

**5. Feeding in Spotted Scat Following the Optimal Foraging Theory**

Spotted scat have showed the selection of food in order to maximize the profitability following the optimal foraging theory in relation to the feeding structure morphology. Fish larvae forage selectively prey items that fall within a preferred size range that is governed by mouth gape. The spotted scat larvae selected microphytoplankton especially diatoms and cyanobacteria were dominant prey items although lower nutrition value than zooplankton. Microphytoplankton were easily captured compared the higher to handling times in zooplankton. The development of swimming ability in larvae limited their ability to actively search and capture food items. Thus spotted scat larvae dependent on surrounding prey items. In addition, the preference for microphytoplankton in corresponded to spotted scat larvae to high density of microphytoplankton in Pak Phanang mangrove forests. According to Holling's Functional Response, larvae increases in consumption as over a threshold density. In larval feeding preference experiment, *Chaetoceros* sp. were chosen predominantly due to their high density (1,929 cells/ml). This species is single cell with optimal prey size (6-24 μm) in relation to the mouth gape. Therefore, the feeding in larvae achieved a maximum net energy gain due to high prey density and minimum energy cost due to less searching and handing time. Larvae feed upon progressively larger-sized items of food as they increased in length and weight. To some extent this is due to the increase in mouth gape (Gerking, 1994).

Juveniles feed on various food items relation to mouth width directly and they often selected prey size at high energy gained corresponded to zooplankton and benthos were found increasing. In addition, large prey items more nutrition value than small prey items. The large size of prey items were found such as mysid, lucifer, insect larvae and polychaete correlated to the increment in rows of villiform teeth and number of gill rakers. The abundance of prey items was also important, consumption increasing with prey density due to capture times and handing time reduce the payoff. The consumption does not increase beyond upper density (Levinton, 1982). From juvenile feeding preference, *Chaetocreos* sp. were firstly selected due to their higher density (3,845 cells/ml). *Skeletonema* sp. and rotifers were chosen in respective order.

Adult spotted scat have high development feeding morphology structure including the increase in rows of teeth and a number of gill raker increasing, size of stomach, number of pyloric caeca and intestinal length. This development allowed adult spotted scat to feed on more dirversed prey items more than larvae and juvenile stages. The diets whoed increased quantity and occurrenced of benthos namely taniadacean and *Onchidium* eggs and detritus than juveniles. Adult spotted scat selected the nutritionally favorable and energy gained prey. From the preference experiment, adult spotted scat selected according to prey size and density of prey items. Adult spotted scat selected *Skeletonema* sp., *Chaetoceros* sp. and rotifer respectively. *Skeletonema* sp. was selected due to chain-like morphology of them easily encounter and catch. Furthermore, the densities *Skeletonema* sp. was highest. Densities of *Skeletonema* sp. were 6,460 cells/ml meanwhile *Chaetoceros* sp. 1,954 cells/ml and rotifer 4 individuals/ml. The results indicated adults selected on abundant profitable food.

## E. Conclusion

Spotted scat demonstrated the ontogenetic changes in each stage and followed the optimal foraging theory. Beginning of the width of mouth gape increased according to size. Fish selected optimal prey size suitable to mouth gape. Teeth are mainly villiform teeth. The numbers of rows were increased. The development of teeth on the jaw implied that the prey items must be easily captured and digested independently of these mechanisms. The short gill rakers were developed to collect and filter food. The large stomach showed the consumtion of large volume of food. The pyloric caeca as an adaptation to increase the absorption surface, the nutrient uptake capacity of the gut and allowed to optimize digestion of diversed prey items. As fish grew, the number of pyloric caeca also increased. In addition, the ratio of intestine length/standard length increased showing the characteristic of omnivorous fish. Most of the ontogenetic changes reflect morphological changes, particularly the increase in mouth size and the improvements in locomotory and sensory abilities. With these improvements, the ingested size of the prey that can be increases.

The ontogenetic changes related with optimal foraging theory on the present of food items in diet. Spotted scat selected food item that maximize fitness and energy gain. Prey density is the major factor for the selection of food in all stages. As the density of prey increase, the number attacked increases. Spotted scat also spent some of the available time in capturing and handling prey. At a sufficiently high prey density, all the time available for foraging will be taken up. Density of prey items and prey capture in spotted scat followed Holling's functional response. Larvae and juveniles presented feeding in Type 3. They focused most of their attention on more abundant foods, switching to less common food only when it exceeds some threshold density. Moreover they required some learning to exploit food at a maximum rate. At low food densities they do not have sufficient exposure to a particular food item to fully develop their searching and handling skills. Adult spotted scat showed feeding as Type 1 which feeding rate increases linearly as food density increases and then levels off abruptly at some maximum feeding rate.

Ontogenetic change in this fish was evidenced. In larval stage, they predominantly feed on microphytoplankton in the water column. Juvenile fish, transitional stage feeding both in water column and mangrove floor, feed on resuspended benthic diatoms, zooplankton, benthos and detritus. Adults, feeding mainly in the midwater level and mangrove floor, with most diversed prey items ranging from microphytoplankton, protozoans, zooplankton, benthos and detritus. The latter two prey items greatly increased in adult diets. In addition, organic detritus were found in stomach content indicated that spotted scat feed on microphytoplankton and plant organic detritus. The results related to high organic detritus in form of forest biomass in the mangrove plantations of Pak Phanang Estuary.

Spotted scat from this area showed flexibility in the feeding ecology. Being omnivore and opportunistic feeder, their diets ranged from microphytoplankton, protozoans, zooplankton, benthos and detritus. Spotted scat have feeding adaptation and flexibility in food item responding to changes in the availability or profitability of potential prey. They switch from one type of prey to another as the relative abundance of the prey types changes. Prey items were more diversed during high salinity periods. During the low salinity period, adult spotted scat in estuarine waterways feed predominantly on *Zoothamnium* spp. The diets during high salinity period were more diversed. In preference experiments also showed flexibility in food items. They are flexible in their choice of foods responding to changes in the availability or profitability of potential preys. *Chaetoceros* sp., diatom, is the reliable food source of optimal prey size and high density for larvae and juveniles. Diet selection in adult spotted scat depends on the density of the more profitable prey. *Skeletonema* sp. was the first choice. *Chaetoceros* sp. and rotifers were chosen next.

# CHAPTER IV

# HISTOLOGICAL ADAPTATIONS IN DIGESTIVE SYSTEM AND FEEDING EFFICIENCY IN SPOTTED SCAT

## A. Introduction

Spotted scat *Scatophagus argus* utilized the Pak Phanang mangrove forests for feeding ground. These fish feed in the mangrove area due to high diversity and abundance of food sources. Spotted scat from this area showed flexibility in the feeding ecology. Being omnivore, their diets ranged from microphytoplankton, protozoans, zooplankton, benthos and detritus. They switch from one type of prey to another as the relative amount of the prey types changes. During the low salinity period, adult spotted scat predominantly feed on *Zoothamnium* spp. The diets during high salinity period were more diversed. Ontogenetic change in this fish was evidenced. In larval stage, they predominantly feed on microphytoplankton in the water column. Juvenile fish, transitional stage feeding both in water column and mangrove floor, feed on resuspended benthic diatom, zooplankton, benthos and detritus. Adults, feeding mainly in the midwater level and mangrove floor, with most diversed prey items ranging from microphytoplankton, protozoans, zooplankton, benthos and detritus. The latter two prey items greatly increased in adult diets. The ontogenetic differences in feeding habits have resulted from acquiring high energy diets to accompany growth and changes in the morphology of feeding structure and digestive system. Histological study of the feeding structure morphology and digestive system would provide an in depth understanding on how the development of digestive system allow this fish to feed on diversed food sources. Prey selection in spotted scat followed to certain extent of the optimal foraging theory based on size of prey, prey density and time and energy spent in prey capture. The goal of digestibility and assimilation efficiency study was to predict whether the composition and quantity of food consumed determine the energy available to this fish. This provides the comparative measurement on nutritional quality of the food items as well as their suitability as food for spotted scat. The integrated results on the feeding ecology in spotted scat are important in determining the trophic role of such fish in the complex mangrove food webs.

## B. Literature Review

### 1. Histology of Feeding Structure and Digestive System in Fish with Emphasis on Omnivorous Fish

The digestive system of fish is basically composed of the digestive tract and digestive glands. The digestive tract of teleosts has attracted considerable interest because of its diversity of form, related to diet. Therefore, the histology of the tract has been investigated, either descriptive (Morrison and Wright Jr, 1999), or related to feeding habits (De Silva *et al*., 1980). The digestive tract extends from the mouth to the anus as remarkably coiled and segmented tube in some forms or as a relatively straight and undifferentiated tube in other. The following segments are generally distinguished in the digestive tract: oral cavity, pharynx, esophagus, stomach and intestine. The liver, pancreas, pyloric caeca and gall bladder are the accessory organs.

The whole digestive tract itself is lined by a mucosal epithelium, which associated a basement membrane, a delicate layer of connective tissue, the lamina propria, and smooth muscle fibers, the later foreshowing the muscularis mucosae. A layer of areolar connective tissue forms a submucosa, and in this, or in the propria, fibers may concentrate to form a more or less homogeneous layer, as the stratum compactum. The muscularis segregate into two to three concentric layers of muscle fibers distinctively organized in circular, longitudinal, and occasionally oblique orientation with the digestive canal. Sphincters and valves along the canal are usually formed by the thickening of the circular smooth muscle coat. The serosa is composed of a simple flat epithelium. This membrane is extend as the mesentery and covers the external surface of the digestive canal. A layer of loose connective tissue is located beneath the serous membrane (Takashima and Hibiya, 1995).

#### 1.1 Oral cavity

It is remarked that *Oreochromis niloticus*, omnivorous fish, has the oral cavity is lined by mucosal epithelium. Special structures or derivatives are observed a number of club cells and goblet cells. The mucosa is stratified squamous non-keratinizing epithelium with cuboidal to columnar basal germinativum and flattened surface cells. Under the mucosa, the submucosa is made up of connective tissue, nerve and blood vessels. The oral cavity, in addition to serve as food passage is concerned with passage of water which is quickly passed through gill slits and out of the digestive tract (Herrera, 1996).

**1.2 Esophagus**

The esophagus is the short narrow muscular tube that transports food from the mouth to the stomach. It has the same layers as the rest of the digestive tract. The esophagus wall of *O. niloticus* consists of the following layers: mucosa, submucosa, muscularis and serosa. The mucosa is non-keratinizing stratified squamous epithelium with well developed goblet cells. A thin lamina propria is identified beneath the mucosa. The submucosa is vascularized loose connective tissue. The muscularis layer has striated muscles arranged in the stratum circular and longitudinal. A thin adventitia of loose connective tissue serves as the serosa (Herrera, 1996). The striated muscle layers of the esophagus changed abruptly to typical gastric glands in the main, sac-like cardiac portion of the stomach (Morrison and Wright Jr, 1999).

**1.3 Stomach**

The stomach of *O. niloticus* is divided into cardiac, fundic and pylorus. The cardiac is thick-walled with mucous glands (Herrera, 1996). On the ventral surface of the stomach the tubular glands gradually changed to gastric glands, although a well developed region of large goblet cells remained at the neck of the gastric glands throughout the stomach (Morrison and Wright Jr, 1999).

Fundic: The mucosa lining is made of columnar cells with basal nuclei. This layer invaginates to form gastric pit that leads to gastric glands. The lamina propria is loose connective tissue interspersed between bodies of gastric glands. The mucous cells in the tubular glands and the neck cells of the gastric glands probably protect the mucosa from the very acid contents of the stomach. Neck cells secreting acid sulphated carbohydrates were described in an *Oreochromis* sp. polyhybrid by Caceci *et al.* (1997); Gargiulo *et al.* (1997). The muscularis mucosa is a thin layer of inner circular and outer longitudinal muscle cells. The submucosa extends into the folds of the stomach and contains collagenous and elastic fibers, blood and lymph vessels and nerves. The muscularis is formed by two layers of muscles, circular and longitudinal layers. The serosa is a thin layer of loose connective tissue and mesothelium (Herrera, 1996).

Pylorus: The large rugae of the fundic become smaller in the pyloric region. There are abundant gastric glands in this area. The lamina propria is loose connective tissue outer to which is the very thin muscularis mucosa. The muscularis layer is thick and formed the circular and longitudinal layers. The serosa is loose connective tissue covered by mesothelium (Herrera, 1996). The striated muscle of the muscularis of the pyloric region extended only a short distance into the main portion of the stomach and the smooth muscle wall was thick in the transitional region from tubular to gastric glands. At the pyloric sphincter there was an abrupt change from tubular glands to the intestinal epithelium, which consisted of simple epithelium with small goblet cells (Morrison and Wright Jr, 1999). Al-Hussaini and Kholy (1953) described a pyloric region of the stomach with tubular glands and Caceci *et al.* (1997) described an initial and terminal region with tubular glands, although they stated that the latter did not contain mucous cells. However, we found that the region with tubular glands consisting of mucous cells was continuous from the entry of the esophagus, across the anterior part of the stomach to the pyloric valve, essentially providing a by pass circumventing the sac-like portion of the stomach.

The experimentally introduce potassium ferrocyanide and ferric ammonium citrate into the stomach of *O. mossambicus* to estimate the amount of acid produced had been reported (Fish, 1960). This regurgitation may be possible because of the by pass region, since *O. mossambicus* is closely related to *O. niloticus*, and shared the resemblance in the by pass region in the stomach. The mucous secretion of the tubular glands would enable rough particles to pass along the tract easily, and striated muscle would possibly make voluntary regurgitation. Passage of material into the intestine could be prevented by the pyloric valve.

**1.4 Intestine**

In *O. niloticus*, the junction which is found between the stomach and intestine in *O. niloticus* is short and narrow. Mucosal folds lined with columnar epithelial cells are interspersed with numerous globlet cells. Presence of the transition zone effectively prevents the immediate passage of food materials from the stomach to the anterior intestine to undergo final digestion. Food of *O. niloticus* which is usually in the form of plankton and water vegetation e.g. algae, is not digested successfully by stomach gland secretions. They remain stored in the stomach for sometimes to allow swelling of the cell wall of the plant food, which facilitates to digest by intestinal enzymes. The intestine is long, permitting prolonged contact between food and enzymes as well as between the absorptive epithelial cells and the digested products. There are three regions, duodenum, jejunum and ileum intestines.

The duodenum, the mucosa has a few papillous fold. The epithelium is simple columnar and differs from the surface epithelium of the stomach by the presence of more than one cells type as columnar cells and goblet cells. The lamina propria and submucosa are areolar connective tissue. The circular and longitudinal muscularis layers are well defined. Serosa is thin areolar tissue with mesothelial covering. The anterior intestine, the common bile duct open. Jejunum portion, the folds are taller and often papillous. The histology is generally similar to the anterior intestine. Ileum portion, the architecture is essentially similar to the anterior intestine but the papillous folds are either very short or absent. There are a number goblet cells. Pancreatic acini may be seen attaching to the serosa and mesentery (Herrera, 1996).

**1.5 Liver**

The liver of *O. niloticus* is the largest organ and the largest gland, next to the stomach. It develops as an outgrowth of the foregut, lying in the pathway of the vitelline veins. It is covered by a connective tissue capsule, Gilsson's capsule. The parenchyma of the liver is composed of spongy network of large polyhedral cells with supporting reticular fibers. The nuclei are darkly stained and the cytoplasm is granular. These are the cells involved in bile synthesis, storage of nutrients, detoxification and blood protein synthesis. Sinusoids, bile ducts and other blood vessels are randomly distributed between the hepatic parenchyma. Sinusoids are highly permeable which irregularly dilated the vascular spaces lined by discontinuous layer of fenestrated endothelial cells and kupffer cells. Arteries walls have relatively thicker than corresponding veins. The excretory duct system of the liver consists of minute channels or grooves in lateral surfaces of hepatocytes. Bile canaliculi are the channels where hepatocytes join their surfaces. This is done by means of tight junction to from spaces which bile is secreted (Herrera, 1996).

**1.6 Pancreas**

In *O. niloticus*, the pancreatic tissue is spread over the mesenteric fat tissue surrounding the liver and the intestinal regions. Interlobular ducts merge to form larger pancreatic ducts running alongside the bile duct before joining the intestine. The pancreas is a mixed exocrine and endocrine gland, the two functions being performed by different cell types. The exocrine portion is a compound tubular gland of irregular acinar cells arranged. Small scattered groups of the endocrine portion are the islet of Langerhans. The exocrine pancreatic acinus or alveolus is composed of cells around a lumen. Highly polarized, they have a spherical nucleus. The zymogen granules in each cell are variable in number. Acini are surrounded by a basal lamina supported by a sheath of reticular fibers, with blood vessels, lymphatics, nerves and excretory ducts.

The islets of Langerhans vary greatly in size. Enclosed by fine reticular fibers, they are scattered as irregular spheroidal masses of pale-staining cells with rich vascular supply. The cells are arranged as irregular cords. These arise as outgrowths from the walls of pancreatic ducts during embryogenesis (Herrera, 1996).

**1.7 Gall bladder**

The gall bladder is a blind, pear shaped diverticulum of the common bile duct. The wall consists of the following layers: a mucosa composed of simple columnar epithelium and lamina propria, smooth muscle layer, perimuscular connective tissue and serous membrane. The common bile duct is lined by simple columnar epithelium with goblet cells. The submucosa layer is inner to the muscularis. The common bile duct carries the bile stored in the gall bladder to the intestine (Herrera, 1996).

**2. Digestion Efficiency**

Digestion is the process by which the ingested food material is broken down to simple, small, absorbable molecules. This task is performed primarily by the digestive enzymes. Digestive fluids and enzymes are part of gastric, pancreatic, bile and intestinal secretions. Digestibility is the quantification of the digestive processes. It gives a relative measure of the extent to which ingested food and its nutrient components have been digested and absorbed by diffusion and active transport. Diffusion may occur either as facilitated or as simple diffusion. Facilitated diffusion occurs where there is a carrier system that allows the compound to move across an otherwise impermeable membrane. Simple diffusion does not require a carrier or energy. Lipids are examples of compounds that are absorbed into intestinal epithelia by simple diffusion. The total and/or dry matter digestibility refers to the degree of digestibility of the complete diet and/or the ingredient. Nutrient digestibility refers to a specified nutrient such as protein, lipid, amino acid or carbohydrate of the diet and/or the ingredient. Assimilation efficiency (the percentage of a food ration that is assimilated after loss to feces (Brett and Groves, 1979)) ranges from 67 to 99% for fish larvae, whereas assimilation efficiency ranges from 80 to 90% for adults. Coefficients of utilization (the fraction of matter or energy retained after losses to defecation of feces as well as metabolic excretion of urine (Winberg, 1956)) for fish larvae are also generally lower than they are for adults. The coefficients of utilization range from 9 to 80% for larvae, whereas coefficients average about 70% for adults (Ware, 1975).

Digestion of protein begins in the stomach in species which possess this structure. The endopeptidase activity of the gastric juice renders proteins soluble and more readily digested by pancreatic and intestinal proteases. In the intestinal digestion of proteins, trypsin and chymotrypsin from the pancreas are of major importance. Polypeptides formed by their interaction are further split by pancreatic carboxypeptidases and by intestinal peptidases. Enzymes such as elastase and collagenase may digest special proteins (Matthews, 1975). Protein and peptides in the intestinal content are probably also taken up to some extent, without previous degradation, by pinocytosis or related processes. Thus in the intestine, administered protein was found to be absorbed in the distal region, in which the epithelial cells specialized for the uptake of large molecules. The protein digestion leads to a mixture in the intestinal lumen of low molecular peptides and amino acid. Fish can not make all their needed amino acids, and depend upon the correct protein source to obtain them. Depending upon the kind of fish, fish get their proteins in plant and animal materials and are comprised of amino acids. Individual amino acids are readily absorbed against concentration gradients and their absorption appears to be coupled with the transportation of inorganic ions (Smith and Lane, 1971). Protein requirements generally are higher for smaller fish. As fish grow larger, their protein requirements usually decrease. Protein used for energy and life support rather than growth. For vigorous health growth, young fish require 50% or in their diets. Herbivores need 15-30 percent protein in their diet whereas carnivores need at least 45 percent protein. While omnivorous fish normally feed on abundant live organisms, rich in proteins which provide a valuable energy source (Moyle and Cech, 1982).

Fat digestion, lipase enzymes activity has been found in extracts of the liver and pancreas, pyloric caeca and upper intestine. Lipase activity is mainly in the intestine and the site is in the mucosal layer. The progressive breakdown of a fat through various intermediate stages is often catalysed by a single lipase and there is not a precise succession of different enzymes as in proteolysis. The end result of lipolysis of a triglyceride molecule is three molecules of fatty acids. Although fish are able to synthesize some fatty acids from other fats, certain fatty acids must be received in the diet. Natural food organisms such as zooplankton are also a good source of essential fatty acids. Fish typically require fatty acids of the omega 3 and 6 (n-3 and n-6) families. Marine fish typically do not possess these elongation and desaturation enzyme systems, and require long chain n-3 HUFA in their diets. Other fish species, such as tilapia, require fatty acids of the n-6 family, while still others, such as carp or eels, require a combination of n-3 and n-6 fatty acids. Carnivorous fish require lipid no more than 8% in their diet, while herbivores need no more than 3%. (National Research Council, 1993; Jobling, 1994).

Carbohydrate digesting enzymes from the pancreas and in the intestinal epithelium transform oligo- and poly-saccharides into hexoses and pentoses. Accordingly, herbivorous fish often exhibit higher carbohydrate activities, apparently to digest the storage carbohydrates of macroalgae, which can contain up to 50% carbohydrate (Horn *et al*., 1986), omnivorous fish present higher amylolitic activity than carnivorous species (Stone, 2003; Krogdahl *et al*., 2005). Ferna´ndez-Reiriz *et al*. (2001) found that, among sparid fish, herbivore exhibited higher $\alpha$-amylase activity than the carnivores examined. Herbivorous fish are more efficient users of carbohydrates. Carbohydrates are important because they are essential for the conversion of amino acids and fats into various other components required for normal function. While carbohydrates are an important part of the diet, not all fish can utilize carbohydrates efficiently. Due to the fact that fish can produce carbohydrates from lipid and protein, they do not need carbohydrates in the diet for normal growth and functions. Carbohydrates should not constitute a large part of the diet. The utilization of dietary carbohydrate has also been found to vary with the complexity or chemical structure of the carbohydrate source used having a more beneficial effect on growth than monosaccharides (Anderson *et al*., 1984; Robinson and Wilson, 1985). The ability of carnivorous fish species to hydrolyze or digest complex carbohydrates is limited due to the weak amylotic activity in their digestive tract (Spannhof and Plantikow, 1983). Warm water omnivorous or herbivorous fish species such as tilapia (*O. niloticus*), and eel (*Anguilla japonica*) have been found to be more tolerant of high dietary carbohydrate levels. The dietary carbohydrate being effectively utilized as a dietary energy source or excess stored in the form of body lipid (Robinson and Wilson, 1985; Degani *et al*., 1986). An excess of carbohydrates in the diet of fish is known to cause liver degeneration and associated diet-related diseases and deter proper growth.

### 3. Trophic Role of Fish in Mangrove Food Webs

Many fish exhibit great flexibility in their trophic ecology, for example, ontogenetic, diel and seasonal changes in diets composition. Wootton (1999) reported that the flexibility of fish diets can generate complex food webs and thereby make it difficult to categorize many species of fish in terms of the well-established ecological concept of trophic levels. Several detritus-based model food webs are important in the mangrove ecosystem in Figure 4.1. Trophic levels and roles of organisms in mangrove food webs can be divided into the following (Paphavasit, 1979):

1. Heterotrophic microorganisms-bacteria, fungi, protozoa and ciliates. Bacteria and fungi play an important role in the breakdown process of detrital particles. Furthermore they enrich the nutritional values of detritus by increasing the protein content. They are the major food sources for meiofauna.

2. Meiofauna-small organisms in 0.1-1 mm. size range such as nematodes and rotifers. Meiofauna are detrital feeders or indiscriminate feeders on bacteria and benthic diatom. Each major taxonomic group may have different feeding types, with each species feeding on various material in the sediment. Small tubellarians may be the top of the food chain in same systems. As active predators they will attack larger forms and either swallow their prey whole or suck out the prey with strong jaws and a muscular pharynx, respectively. Many macrofauna may skip the intermediate meiofauna link and feed directly on bacteria and protozoa. They will occupy the

same trophic level as their smaller meiofauna are rapidly broken down by bacteria action, these will assist in the recycling of nutrients at a low trophic level. Meiofauna are important in the diets of fish in the families: Sillaginidae, Gobiidae, Teraponidae and Leiognathidae (Blaber, 2000).

3. Herbivore-those that assimilate plant material directly by grazing or consuming microorganisms or meiofauna from detritus. Herbivores are organisms that assimilate plant material directly by grazing or consuming microorganisms or meiofauna from detritus. There are some fish that feed on both microalgae and decaying detritus. These fish will shorten the food chains by replacing the zooplankton or other macrofauna as the critical herbivore link. Mullet, as one of the herbivorous fish, have a pharyngeal filtering device which enables them to suck up surface layers of mud and select the very fine particles. The gut contents consistently had higher organic matter than the deposits on which they were feeding. The fish also feed on microalgae from the surface of the sediment and macrophytes. Estuarine herbivorous fish are those in the families: Hemiramphidae, Sparidae, Siganidae, Gobiidae, Cichlidae and Monacanthidae (Blaber, 2000).

4. Omnivore-those that assimilate both plant and animal material whenever available. Detritus feeders sometimes are categorized into this group. Omnivores are organisms that assimilate both plant and animal material. They usually ingest more plant material than animal material. Omnivore can either feed on herbivore or be on the same trophic level by competing for the detrital food source. There are at least three major types of detritus feeders (a) grinders, (b) deposit feeders, and (c) filter feeders. Amphipods and most crabs are grinders which fed on large pieces of leaf material which are masticated into smaller particles. Polychaetes are usually considered deposit feeders. Bivalves are the best example of filter feeders. Fish in this group are Mugilidae, Teraponidae, Drepanidae, Eleotridae, Gobiidae, Ostraciidae, Scatophagidae and Tetraodontidae (UNDP/UNESCO, 1991; Boonruang *et al.*, 1994; Monkolprasit, 1994).

5. Lower carnivore-those that depend upon animal tissues as food usually small animals. These species, predominantly small fish, feed on the preceding herbivorous and omnivorous groups. This category also includes some wading birds and game fish. The main piscivorous families in estuaries are Belonidae, Carangidae, Carcharhinidae, Centropomidae, Elopidae, Megalopidae, Sciaenidae and Sphyraenidae (Blaber, 2000).

6. Top carnivore-these species from the top of food chain including predacious fish, wading birds, mammals, amphibian and reptiles. Their food derives from all the lower trophic levels, but the most common ingested organisms are from the lower carnivore level.

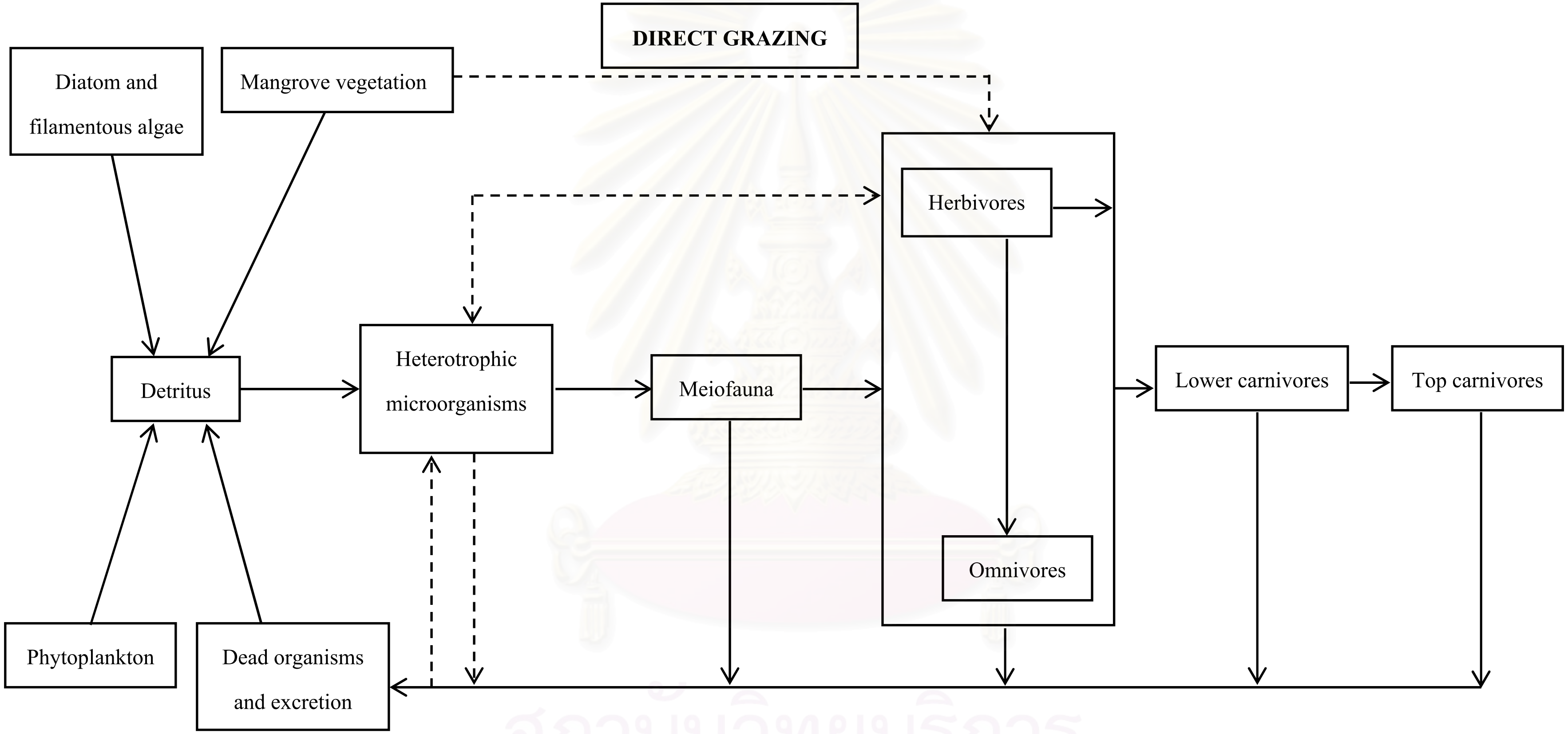



Figure 4.1 Proposed Model of the food web in the mangrove ecosystem. The dark line indicates the main pathway while the dotted line indicates the alternative Pathway (Paphavasit, 1979)

## C. Materials and Methods

### 1. Histology of Feeding Structure and Digestive System

*Scatophagus argus* of three different sizes were obtained for the study: larvae 1-2 cm, juveniles about 2-7 cm and adults more than 8 cm in length respectively. Ten individuals in each group were observed. The whole digestive tract, from the buccal cavity to the intestine, with pyloric caeca, liver, gall bladder and spleen, was taken from the body cavity and fixed in 10% buffered neutral formalin (Figure 4.2).

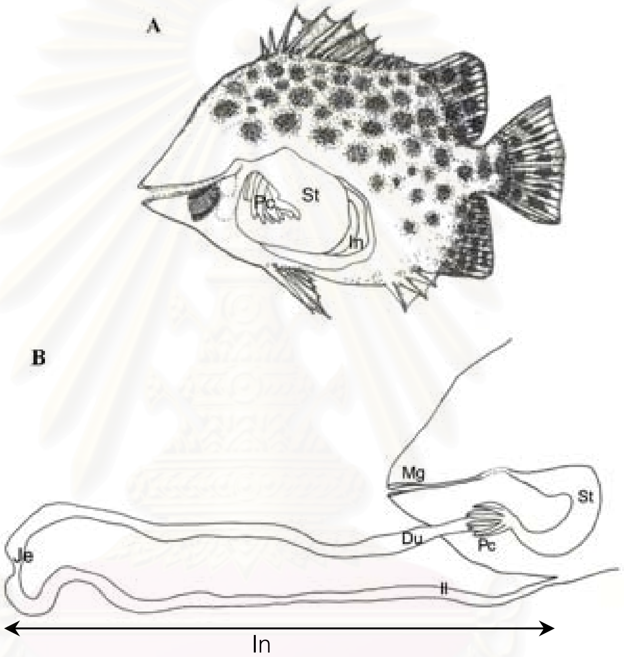



Figure 4.2 Line drawing of the digestive system of spotted scat (A) oriental of the tract in the abdominal cavity, (B) tract extended; Mg=Mouth gape, St=Stomach, Pc=Pyloric caeca, In=Intestine, Du=Duodenum, Je=Jejunum, Il=Ileum

Sections 2 cm long were taken from each of the following regions from the esophagus, cardiac, fundic and pyloric stomach and the duodenum, jejunum and ileum respectively. After adequate fixation, teeth were placed in decalcified solution, formic acid-sodium citrate solution. The specimens were then washed in running water from 4-8 hr before dehydration and embedding. After the specimens were fixed in the 10% buffered neutral formalin solution. They were dehydrated in an ethanol series from 70% to absolute alcohol, then embedded in paraffin. The paraffin embedded specimens were cut at 4 µm and stained by Mayer's Hematoxylin and eosin, Alcian blue and Periodic Acid Schiff (PAS).

The sections of fish were microscopically examined under light microscope. The histological finding was recorded. Histological details were linked to feeding structure morphology. Digestive tract in each size of spotted scat such as size in width and length of tooth and the muscle layer thickness of were analyzed by one-way analysis of variance (ANOVA). A posteriori Tukey's HSD test was used to determine. The calculated coefficients were compared to the correlations coefficients at significance level of $p < 0.05$.

**2. Digestion Efficiency in Different Stages of Spotted Scat**

Fish size 1-2 cm, 2-7 cm and larger than 8 cm classified as larvae, juveniles and adults respectively were reared for the digestion efficiency experiments. Two experimental tanks of 12 litre volume with more than 50 fish larvae each were designated for the rearing of fish larvae. Three tanks of different size namely 12 and 24 litre were used for juvenile and adult fish in order to allow more spaces for the fish. Twenty juveniles and 5 adult fish were used in each rearing tank. The rearing condition set with filtered seawater at salinity of 20 psu, with adequate oxygen supply. Water quality was monitored with daily change of water. Fish were starved for one day before the experiment. Each rearing tank was provided with different food. Two microphytoplankton, *Chaetoceros* sp. and *Skeletonema* sp. were used in the fish larval experiment. In juvenile and adult experiments, rotifers were used as food in addition to microphytoplankton. The experiments were carried out in 4 weeks (Figure 4.3). Feces were collected daily. Food for feeding and feces in total of each 4 g dry weight were analyzed by proximate analysis method.

| | | |
|---|---|---|
| Experiment 1 (1 replicate) | 1.1 | Fish larvae + *Chaetoceros* sp. |
| | 1.2 | Fish larvae + *Skeletonema* sp. |

| | | |
|---|---|---|
| Experiment 2 (1 replicate) | 2.1 | Juveniles + *Chaetoceros* sp. |
| | 2.2 | Juveniles + *Skeletonema* sp. |
| | 2.3 | Juveniles + Rotifer |

| | | |
|---|---|---|
| Experiment 3 (1 replicate) | 3.1 | Adults + *Chaetoceros* sp. |
| | 3.2 | Adults + *Skeletonema* sp. |
| | 3.3 | Adults + Rotifer |

Figure 4.3 Experimental design on the experiment on digestion efficiency in spotted scat

Proximate analysis method (Association of Official Agricultural Chemists, 1990) is the determination of dry matter, ash, crude protein, crude fat and fiber. Moisture is determined by the loss in weight of samples dried in 100 $^{o}$C oven. Ash is the mineral component determined by burning the sample in a muffle furnace at 600 $^{o}$C for 2 hours. Crude Protein is determined by Foss Digestor 200 and Kjeltec$^{TM}$ 2100 which determines the amino nitrogen of a sample. Crude fat is the portion of a sample that is soluble in diethyl ether. Ether extract analyzed by SOXTEX SYSTEM HT 1043 Extraction Unit tecator. Crude fiber is that portion of the moisture and fat free sample that remains after digestion with weak acid and base. Fiber extract analyzed by Gerhardt Model FB56 S/N: GER 4070450.

The results of proximal analysis were %crude protein, %crude fat, %ash and %dry matter led to the calculation of gross energy (GE), apparently digested energy (DE) and apparent digestibility coefficient of energy (ADC) (National Research Council, 1993).

**Gross Energy** = the total combustible energy in a feed, determined by measuring the amount of heat produced. The energy released as heat when an organic substance is completely oxidized to carbon dioxide and water. It is often refer to as “heat of combustion” and generally measured in an oxygen bomb calorimeter.

%carbohydrate = 100- (%crude protein+%crude fat+%ash+%dry matter)

Gross Energy (GE)(kcal/100g) = %crude protein x 5.64+%crude fat x 9.44+%carbohydrate x 4.11

**Apparently Digested Energy** = energy in feed consumed less energy in feces

Apparently Digested Energy (DE)(kcal/100g) = IE-FE
where IE=Intake of food energy (the gross energy in the food consumed)
FE=Fecal energy (the gross energy in the feces)

**Apparent Digestibility Coefficient of Energy** = the percentage of energy consumed in food less energy in feces

% ADC of energy = [(C-F)/C] x100
where C =The total energy consumed in food
F= The total energy lost in feces

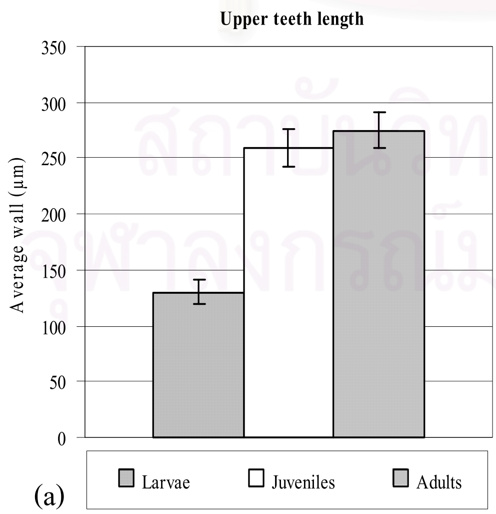
The magnitude of the differences content of proximal analysis from each size of spotted scat was determined with a one-way analysis of variance (ANOVA). A posteriori Tukey’s HSD test at significance level of $p < 0.05$ was used in all tests.

## D. Results and Discussions

### 1. Histology of Feeding Structure and Digestive System Related to Types of Food and Feeding Behavior

#### 1.1 Teeth

The teeth of spotted scat develop in the typical manner of fish. An enameled bud first develops in the epithelial connective tissue overlying the anlagen of the tooth bearing bones. Collagenous dentine then develops beneath the tooth germ or dermal papilla. Next mineralization of dentine proceeds. Finally, the mature tooth develops a bone of attachment as a pedestal. The surface of dentine is usually covered with enamel. Enamel is secreted by enamel organ, which is composed of two layers of epithelial cells, while the tooth is still in tooth germ. Larval teeth of spotted scat at maxilla and mandible are mainly tooth germ and low numbers. Some teeth penetrated the epithelium showed villiform teeth (Lanzing and Higginbotham, 1976). Larval teeth used for grasping rather than masticating food. In larger fish, teeth are many in numbers; all of the teeth are of the same form but different size used for grinding and crushing food such as the pharyngeal dentition of some cichlids that feed by crushing molluscs in striking (Keast, 1978). This results, larval stage has round teeth and a relatively few in number while adult have long teeth and high number (Figure 4.4 and Figure 4.5). The rapid increase of number of jaws and enlarged mouth gape during the first few days will enhance feeding in the larvae by increased size of prey and ingestion. The average of length and width of upper and lower teeth of larvae showed different significant between juveniles and adults ($p<0.05$) (Table 4.1 and Figure 4.7).



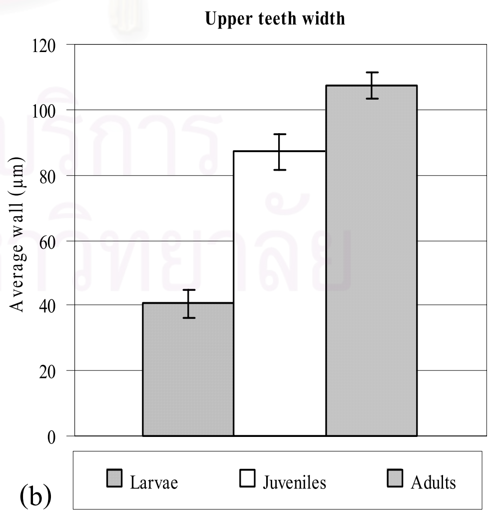
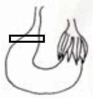
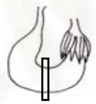
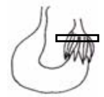
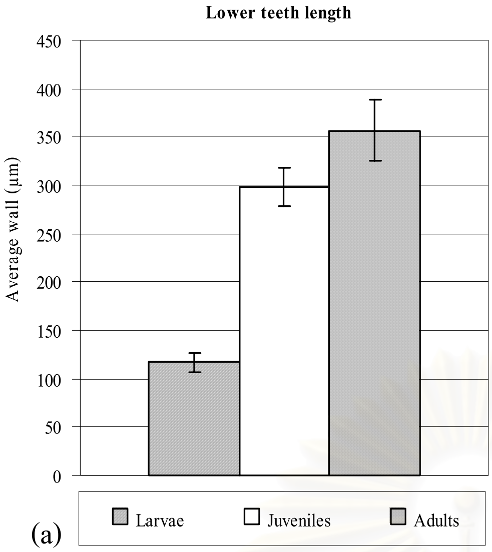




Figure 4.4 The upper teeth sizes in length (a) and width (b) in three stages of spotted scat (Mean±SE) (n=5)

Table 4.1 The histological structure of digestive system in spotted scat (Mean±SE)

| **Digestive system** | **Larvae (n=5)** | | **Juveniles (n=5)** | | **Adults (n=5)** | |
|---|---|---|---|---|---|---|
| **Mouth position** |  | |  | |  | |
| **Average size (µm)** | Length | Width | Length | Width | Length | Width |
| **Teeth in upper jaw** | 129.88±11.24 | 40.49±4.18 | 259.40±16.80 | 87.14±5.42 | 274.77±16.14 | 107.38±4.18 |
| **Teeth in lower jaw** | 117.17±9.68 | 41.16±2.53 | 298.66±19.44 | 90.14±4.40 | 356.85±30.95 | 103.10±8.17 |
| **Average wall thickness (µm)** | Mucosa | Muscularis | Mucosa | Muscularis | Mucosa | Muscularis |
| **Esophagus** | 120.93±2.31 | 43.48±1.76 | 235.07±21.28 | 209.08±17.75 | 301.78±34.62 | 264.77±18.76 |
| **Stomach** |  Cardiac portion | |  Fundic portion | |  Pyloric portion | |
| **Average wall thickness (µm)** | Mucosa | Muscularis | Mucosa | Muscularis | Mucosa | Muscularis |
| **Cardiac portion** | 84.30±2.56 | 31.98±1.20 | 200.06±2.76 | 122.59±5.22 | 240.14±3.11 | 196.61±8.26 |
| **Fundic portion** | 219.24±3.37 | 114.03±4.93 | 250.85±8.32 | 124.27±5.98 | 321.60±4.61 | 244.80±10.50 |
| **Pyloric portion** | 87.94±4.88 | 152.78±9.39 | 146.04±2.91 | 317.64±8.60 | 161.71±2.68 | 601.01±25.06 |
| **Intestine** |   | | | | | |
| **Average wall thickness (µm)** | Mucosa | Muscularis | Mucosa | Muscularis | Mucosa | Muscularis |
| **Duodenum** | 191.31±7.84 | 6.35±0.12 | 263.38±8.96 | 75.65±2.80 | 612.22±12.90 | 109.30±6.50 |
| **Jejunum** | 39.63±1.41 | 15.75±0.62 | 185.95±6.43 | 82.80±5.82 | 320.65±9.42 | 129.88±4.59 |
| **Ileum** | 138.95±8.18 | 74.63±5.38 | 254.34±10.69 | 106.73±4.96 | 406.88±10.59 | 141.41±3.41 |



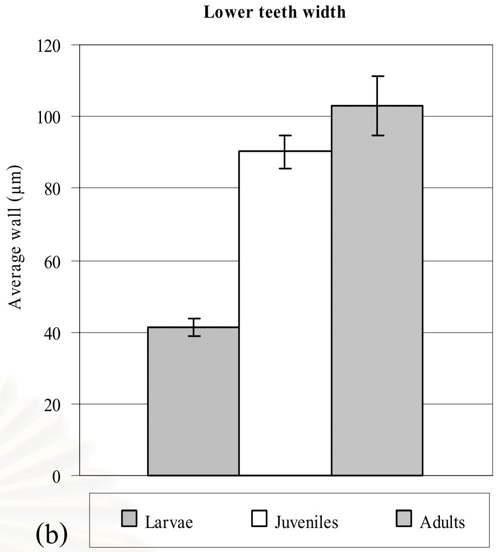




Figure 4.5 The lower teeth sizes in length (a) and width (b) in three stages of spotted scat (Mean±SE) (n=5)

From the results, teeth structure developed for corresponding food namely benthic microphytoplankton, zooplankton and planktonic microcrustacean. Teeth of spotted scat are villiform for crushing or grinding correlated with food items as mainly microphytoplankton. Many omnivorous and herbivorous fish have villiform. Juvenile *Lates calcarifer* with villiform teeth is regarded as omnivore corresponding to the stomach content of mainly microphytoplankton, small fish and shrimp (Food and Agriculture Organization of the United Nations, 1988).

**1.2 Esophagus**

Oral cavity has numerous taste buds and mucous cells for controlling food intake which the distribution and number in each taste zone correlate to specific features of the feeding and feeding behavior. The esophagus, the thickness of mucosa and muscularis layers varied by body size (Table 4.1). The average thickness of mucosa layer of esophagus in larvae showed difference significantly from adults, meanwhile the average muscularis layer of esophagus of larvae showed difference significantly between juveniles and adults ($p<0.05$) (Figure 4.6).

The epithelium of the esophagus is stratified squamous and consists mainly mucous secreting goblet cells, which aids in the passage of food. No digestive enzymes are produced by glands of the esophagus. Goblet cells interdispersed within the epithelium appeared to increase substantially in numbers posterior toward to the cardiac portion and as development proceeded. This is important mechanism for concentrating plankton as secretion of mucus that coalesce the plankton so the fish can swallow it. The mucosa is therefore puckered when the muscle of the tube has not been stretched. A thin lamina propria is identified beneath the mucosa. The submucosa is composted of connective tissue lacking glands somewhat dense than that of the lamina propria. The muscularis consists of striated muscle in the anterior portions and gradually changes to smooth muscle near the transition to the stomach (Figure 4.8 and Figure 4.9).

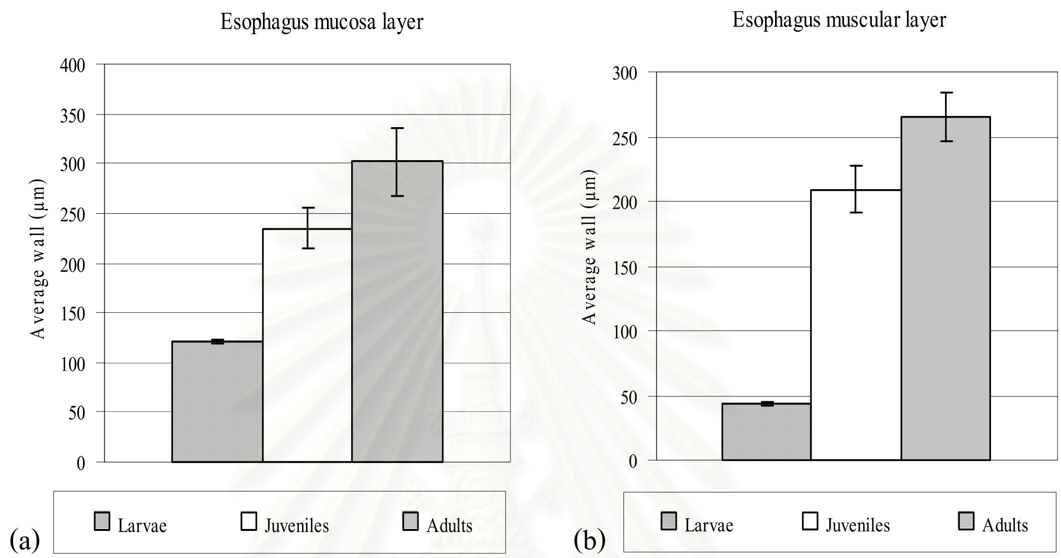



Figure 4.6 The thickness of mucosa (a) and muscular (b) layers in esophagus of spotted scat (Mean±SE) (n=5)

Pasha (1964), however, described large mucous cells and small goblet cells in the esophagus of *O. mossambicus*, may correspond to the two types described here. The two cell types appear to have different secretions, the small goblet cells and the large goblet cells. The small goblet cells were pear-shaped, with basal nuclei, appearing near the surface of the epithelium; whereas the large cells extended to the base of the epithelium. The tunica muscularis consisted of two layers of striated muscle, an outer circular and inner longitudinal, with bundles extending into the submucosa (Al-Hussaini and Kholy, 1953).

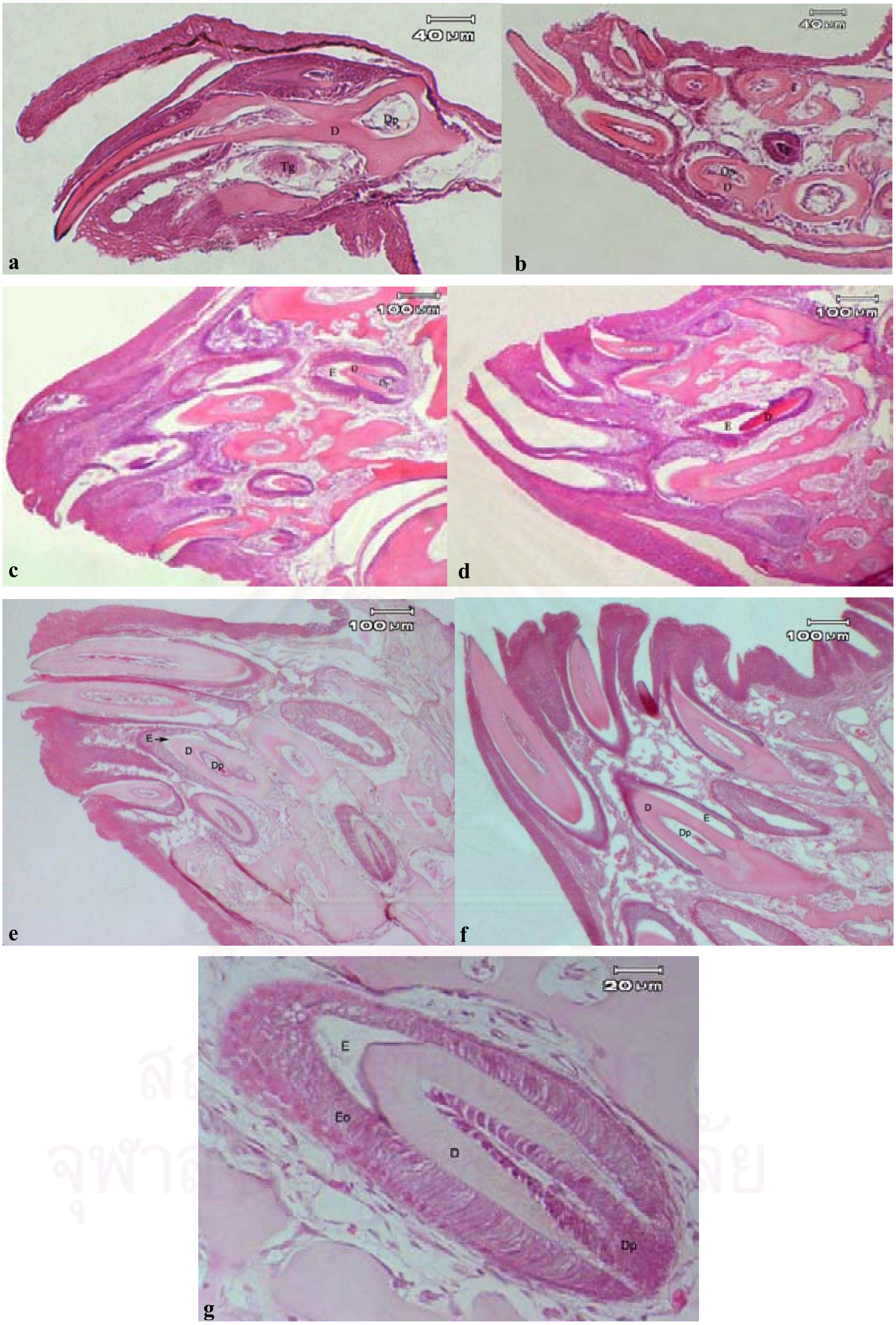



Figure 4.7 Teeth in maxilla and mandible of larvae (a,b), juveniles (c,d), adults (e,f) and the magnified teeth structure (g) of spotted scat; Dp=Dermal papilla, D=Dentin, Tg= Tooth germ, E=Enamel, Eo=Enamel organ; H&E.

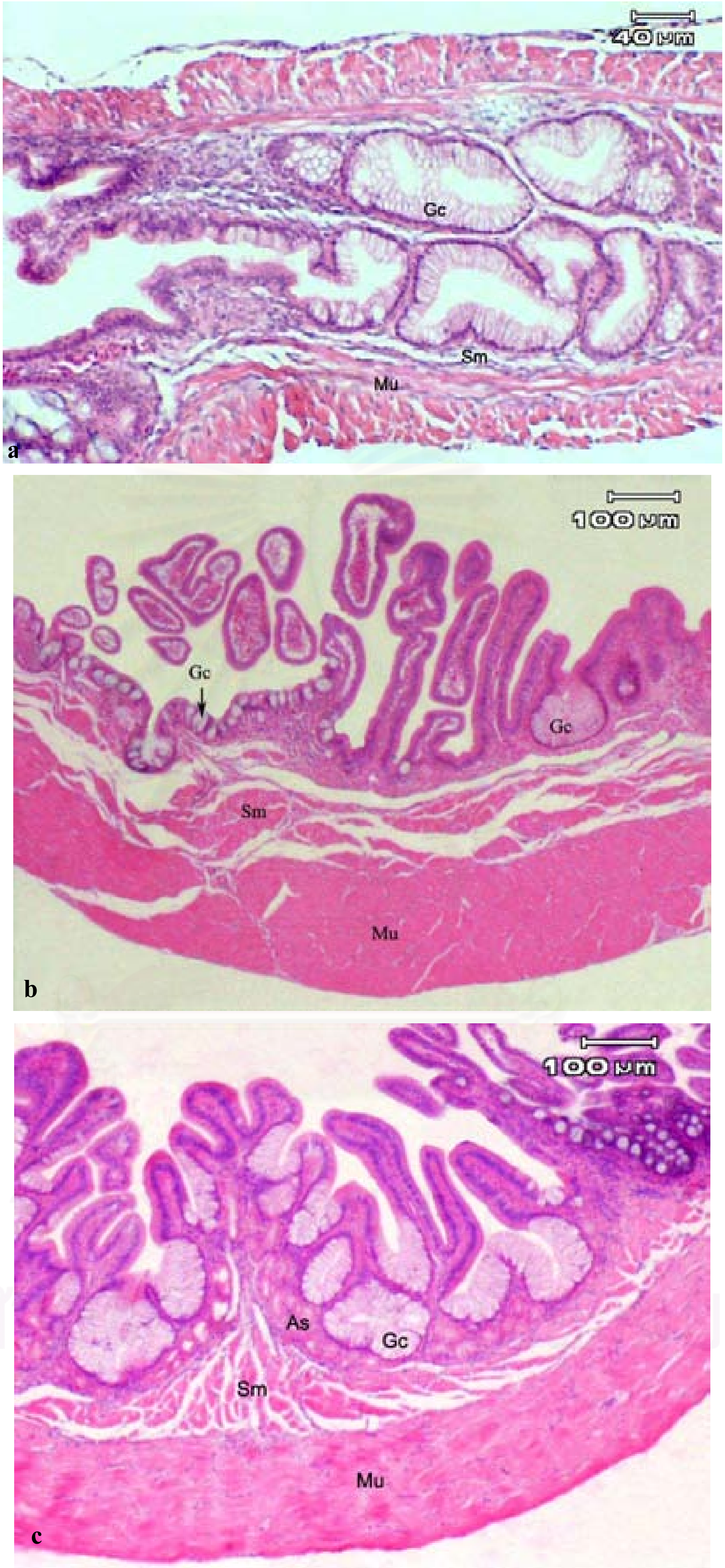



Figure 4.8 Esophagus of larvae (a), juveniles (b), adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, Gc=Goblet cells, As=Alarm substance cells; H&E.

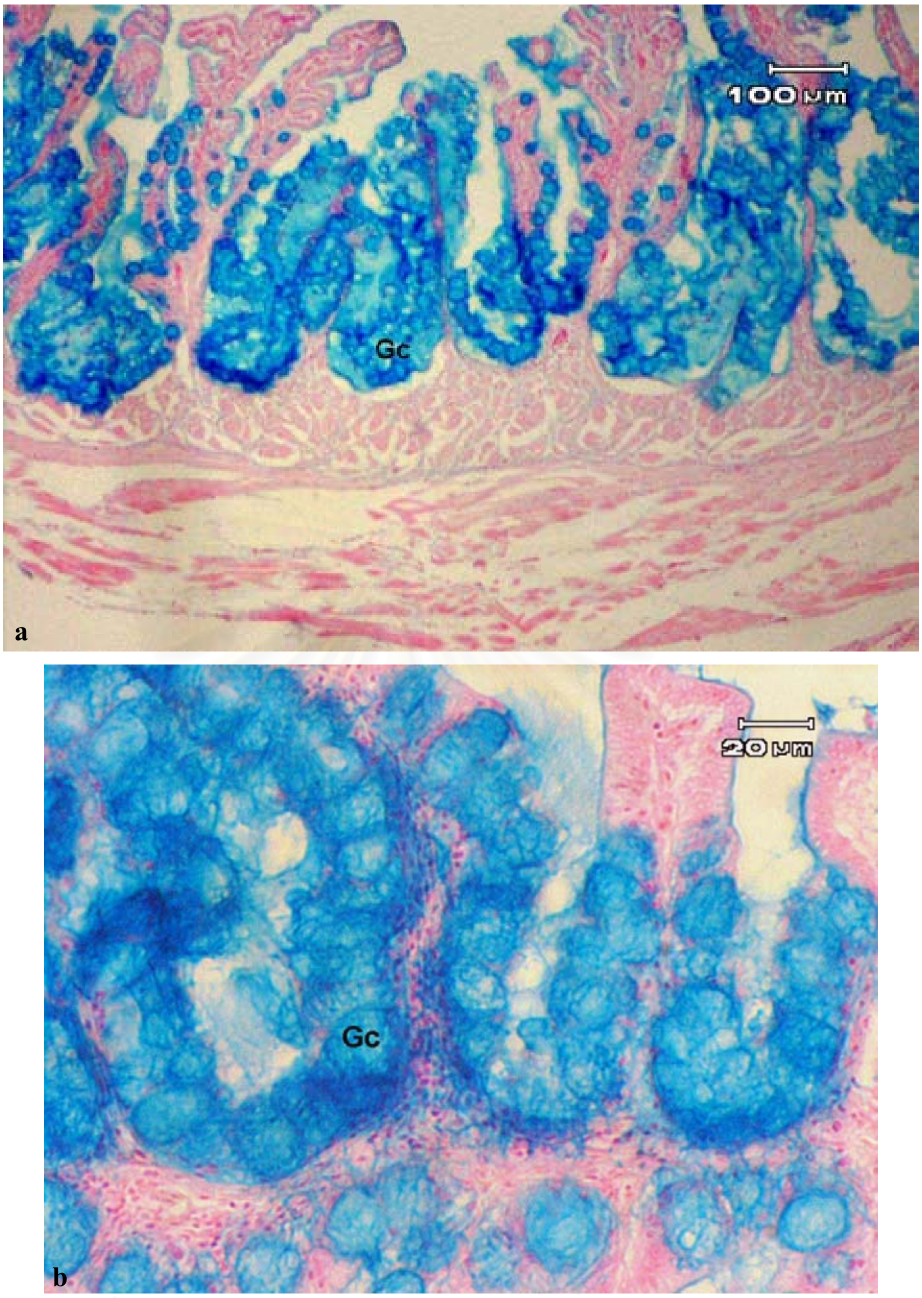



Figure 4.9 The goblet cells in spotted scat respond positively to alcian blue stain (a,b); Gc=Goblet cells.

### 1.3 Stomach

The stomach of spotted scat classified into three parts namely cardiac portion, fundic portion and pyloric portion. Cardiac portion have the thickness of mucosa and muscularis layers were densely followed body size (Table 4.1). The average mucosae and muscularis layer of cardiac portion of three stages showed significantly difference ($p<0.05$) (Figure 4.10). This portion demonstrated well developed of large goblet cells remained at the neck of the gastric glands through all the regions of the stomach.

In adult, cardiac portion has a number of gastric glands higher than larvae. The gastric pits of the cardiac glands are lesser in depth than those of the fundic glands. However, this distinction may not recognize in a routine section. The mucosa is composed of a cuboidal epithelial cells interspersed with mucous-secreting cells lines. This area has a number of goblet cells to protect the mucosa against proteolytic degradation by neutralizing stomach acidity. The submucosae layer has some blood vessels. The muscularis is made up of two layers of smooth muscle, an inner circular and an outer longitudinal layer, with some striated muscle bundles next to the esophagus (Figure 4.11 and Figure 4.12).

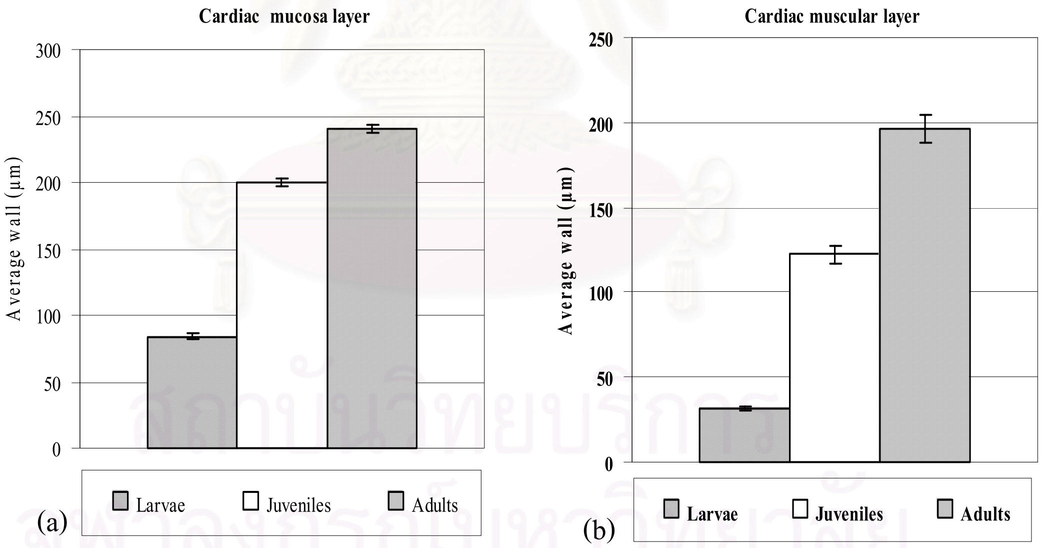



Figure 4.10 The thickness of mucosa (a) and muscular (b) layers in cardiac portion of spotted scat (Mean±SE) (n=5)

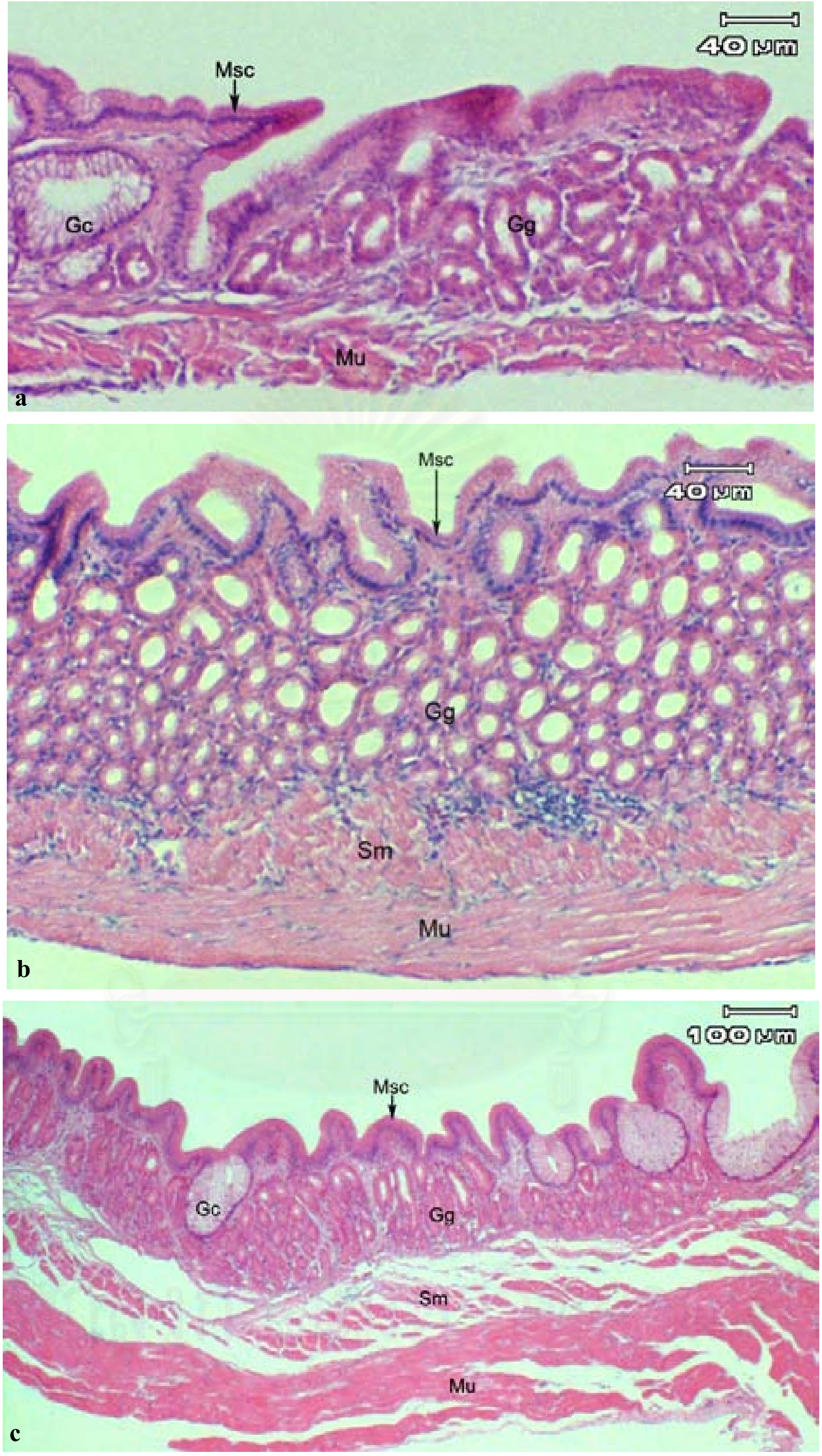



Figure 4.11 Cardiac portion of larvae stomach (a), juveniles (b) and adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, Gc=Goblet cells, Gg=Gastric glands, Msc=Mucous-secreting cells; H&E.

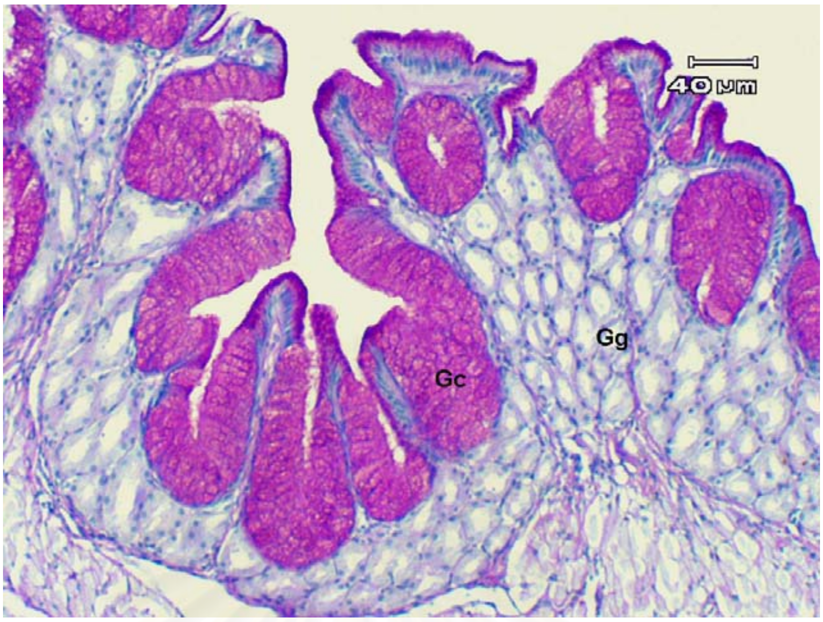



Figure 4.12 Goblet cells and gastric glands in spotted scat; Gc=Goblet cells, Gg=Gastric glands, PAS.

In fundic portion, the average mucosa layer of fundic portion of three stages showed significantly difference, meanwhile the average muscularis layer of adults showed significantly difference from larvae and juveniles ($p<0.05$)(Table 4.1; Figure 4.13 and Figure 4.14). The gastric epithelial cells are secreted to neutral mucins to facilitate the absorption. Gastric glands are markedly increasing secreting acid-peptic gastric juices. When fish grew, a number of gastric glands indicated to increase in number in the fundic stomach. Gastric glands primarily consist of parietal cells and chief cells. Parietal cells secrete hydrochloric acid and chief cells secrete pepsinogen to degrade food proteins into peptides. Pepsinogen is secreted by chief cells and quickly hydrolyzed to pepsin, an active proteolytic enzyme. Thus most of is digested protein in the stomach as a result of pepsin and mucous cells.

The mucosa lining is made of columnar cells with basal nuclei. The gastric mucosa has a structure adapted to function as food storage and digestion. This structure allows the fish accommodating large variations in meal size, by its distension. The distension serves as a powerful stimulus for gastric digestive secretions in fish. It is also possible that this folding pattern may slow down the passage of food in the stomach, and divide the ingested bolus into small size in order to digestion (Osman and Caceci, 1991).

The mucous-secreting cells cover the luminal surface of the stomach and line the gastric pits. The mucous-secreting cells are also found in the wall of the stomach. It is reported that the major function of the mucus is preventing the damage of enzymes, i.e. to reduce self-digestion of the mucosa. The mucous cells in the tubular glands and the neck cells of the gastric glands protect the mucosa from the strong acid contents of the stomach. The submucosa contains collageous and elastic fibers, blood and lymph vessels and nerves. The muscularis is formed by two layers of muscles, circular and longitudinal layers. The serosa is a thin layer of loose connective tissue and mesothelium (Herrera, 1996).

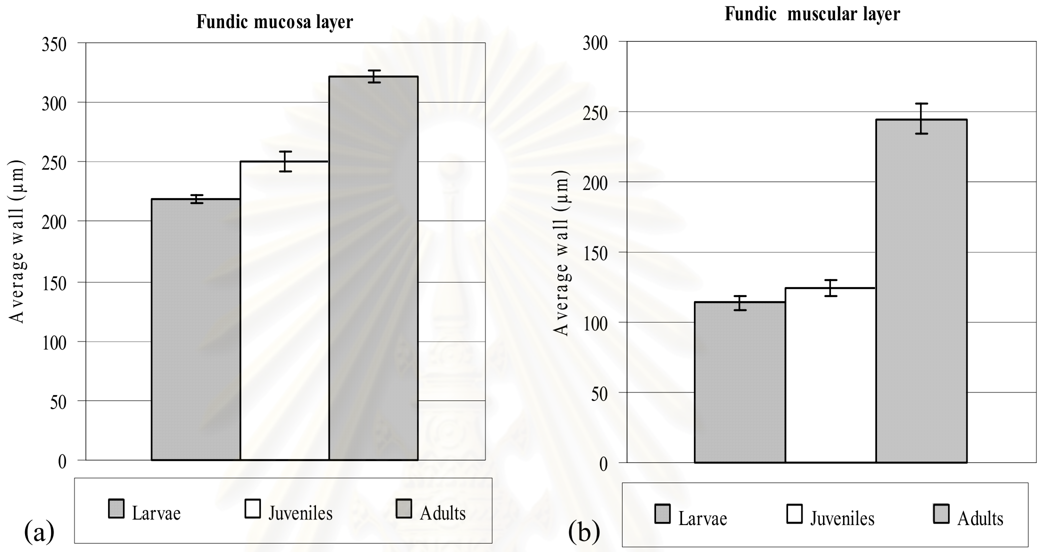



Figure 4.13 The thickness of mucosa (a) and muscular (b) layers in fundic portion of spotted scat (Mean±SE) (n=5)

The pepsins are secreted from the gastric glands in the form of inactive zymogens (pepsinogens) which are activated by acidic conditions (below pH 6). Enzyme extracts from the stomachs of some species of fish have maximum peptic activity in the pH range 4-5, but maximum at pH 2-3 have been reported for other species (Fish, 1960).The level of stomach pH have shown that the stomach contents rarely fall as low as 2-3, except during the latter stages of gastric digestion (Moriarty, 1973). The pH in the stomach of an unfed fish may range from 3-7; it may slightly increase, shortly after feeding. This rising in pH may be due to the ingestion of food with a high buffer capacity or due to water intake during the food intake. Towards the end of the gastric phase of digestion of the pH in the stomach is lower and the reduction in pH are due to the secretion of hydrochloric acid from the gastric glands (Jobling, 1995).

Stomach pH of spotted scat is 6.5-7.0 corresponded to those of omnivorous species. The pH is around neutral or slightly basic meanwhile the stomach pH in carnivorous species is 2.5-3.5 (Çinar and Şenol, 2006). Other herbivorous species of fish depend on the acid lysis in order to gain access to the nutrients contained within the cells of the green and red algae upon their feed.

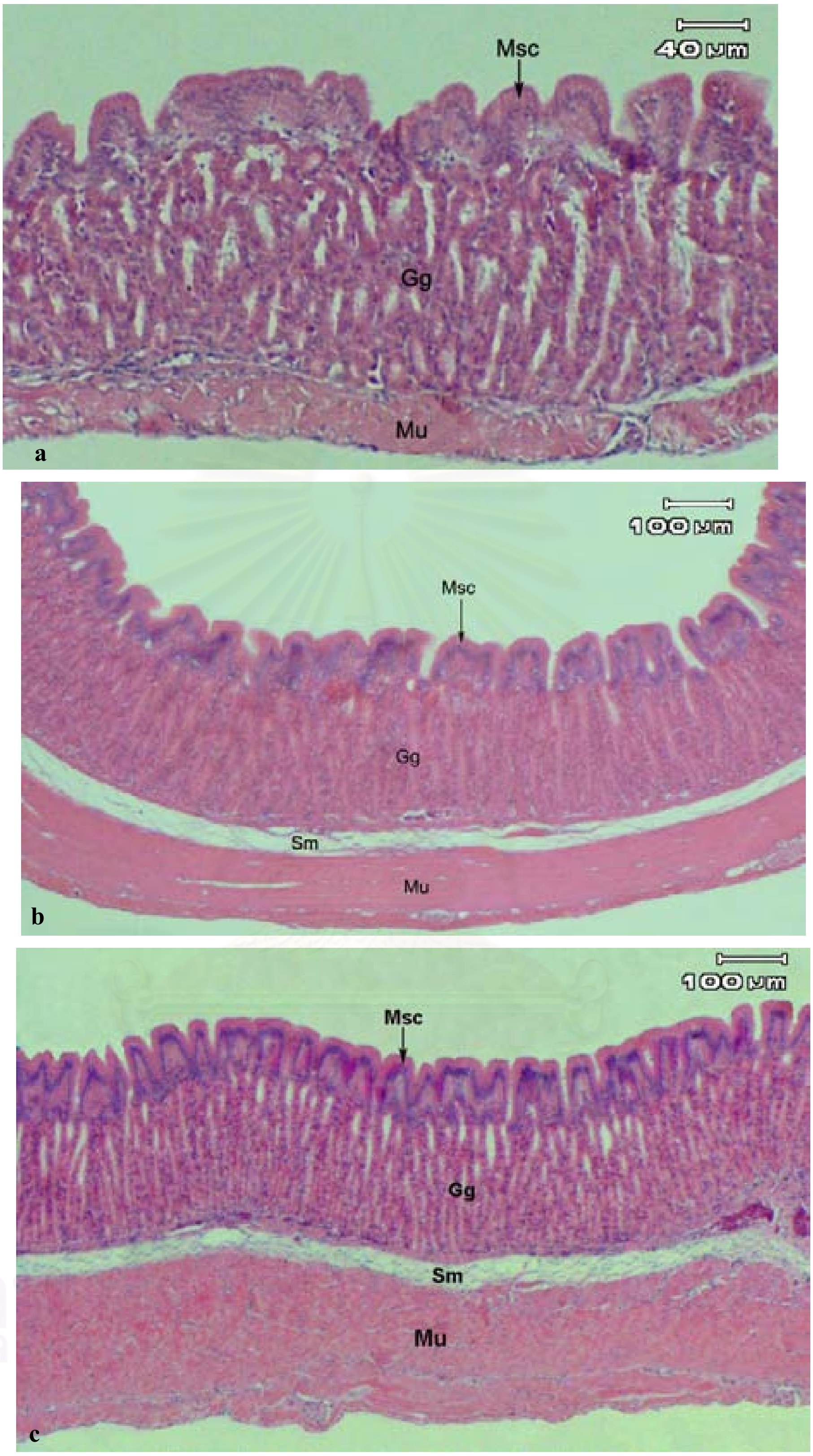



Figure 4.14 Fundic portion of larvae (a), juveniles (b) and adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, Gg=Gastric glands, M=Mucosa, Msc=Mucous-secreting cells; H&E.

The low pH range 1.2-4.3 in the thin-walled stomach results in lysis of the cells walls of the ingested plant material. Thereby their contents are released and enabling to enzymatic digestion.

Moriarty (1973) reported *O. niloticus*, omnivore fish, fed diurnally on microphytoplankton dominated by blue green algae. When feeding started, the algae remaining green color initially throughout the digestive tract. However, acid secretion started in the stomach by lowering the pH at 1.4-3.0. Some algae passed into the sac-like portion of the stomach, where the strong acid conditions could lysed the algal cell walls. Thus they could be digested when entering the intestine. This material is turned brown, while other algae passed along the anterior surface of the stomach directly from the esophagus to the pyloric sphincter and the algae remained green. In stomachless filter-feeding fish such as silver carp, the pH of the gut fluids is usually more than 6. The lack of cellulase in the gut fluids also indicates that it is difficult for them to breakdown cellulose cell walls by enzymatic digestion (Bitterlich, 1985 a,b).

Additionally, small prey organisms are usually broken down and evacuated from the stomach rapidly, so a meal consisting of detritus or small planktonic organisms such as zooplankton will usually be processed more rapidly than the one consisting of molluscs, insects, worms, larger crustaceans or fish. The physical and the chemical properties of different preys have significant effects on the rates of which they are digested and emptied from the stomach.

The pylorus and fundic portion have a sieving function leading to the preferential retention of large food particles in the stomach. Small particles readily pass through the pylorus, but the retention times for larger particles appearing to be related to their sizes, density and the ease that they can be broken down. One consequence of the sieving action of the pylorus and fundic portion is that there is a preferential retention of large indigestible particles in the stomach. These indigestible particles tend to congregate in the fundic region during the course of the gastric digestion. The pyloric portion was folded and lined by a short ciliated columnar epithelium. The muscular layer thickness of the pyloric stomach dramatically increases (Table 4.1). The average of mucosae and muscularis layers of three stages showed significantly difference ($p<0.05$) (Figure 4.15 and Figure 4.16). A few parietal and chief cells are mucous-secreting cells. At the pyloric sphincter there was an abrupt change from tubular glands of gastric glands to the intestinal epithelium, which consisted of columnar epithelium with a number of goblet cells (Morrison and Wright Jr, 1999). Al-Hussaini and Kholy (1953) described a pyloric region of the stomach with tubular glands consisting of mucous cells was continuously appeared from the entry of the esophagus, across the anterior part of the stomach to the pyloric valve, essentially providing a by pass circumventing the sac-like portion of the stomach.

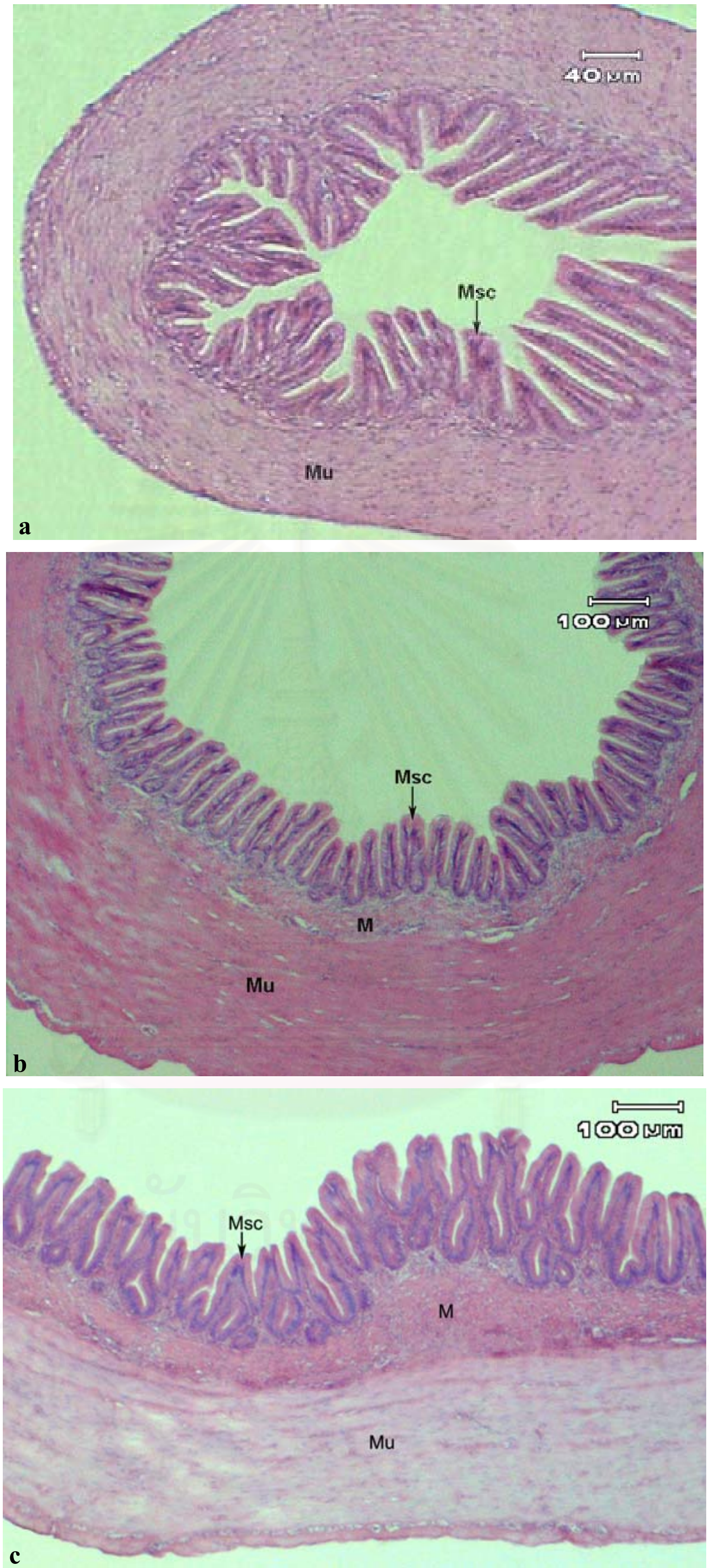



Figure 4.15 Pyloric portion of larvae (a), juvenile (b) and adults (c) of spotted scat; Mu=Muscularis, M=Mucosa, Msc=Mucous-secreting cells; H&E.

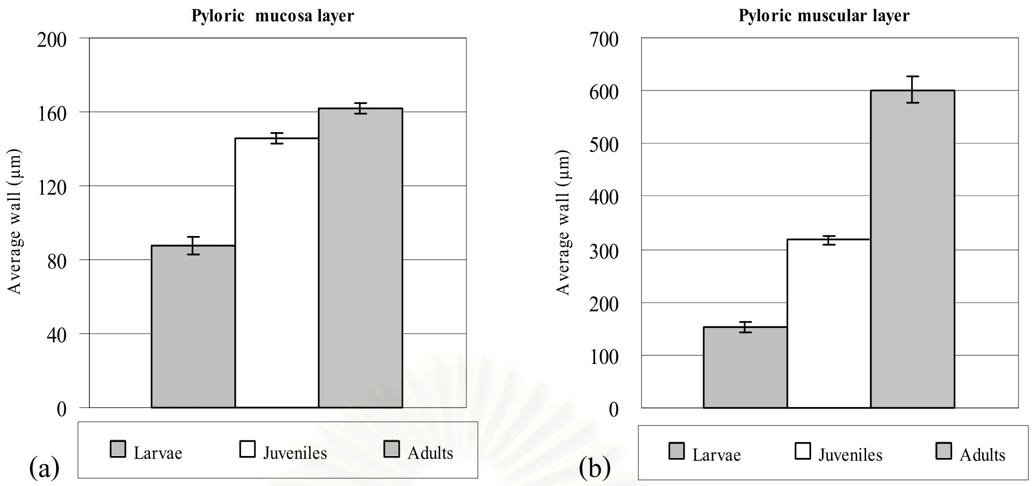



Figure 4.16 The thickness of mucosa (a) and muscular (b) layers in pyloric portion of spotted scat (Mean±SE) (n=5)

The junction of the stomach and the intestine is marked by the pyloric caeca. The mucosa is comprised of a single layered epithelium with columnar absorptive epithelial cells with an evident brush border. The pyloric caeca are consisting of a mucosa has a few branched folds, submucosa, muscularis well-defined, circular and longitudinal muscular layers and the serosa.

Spotted scat feed on zooplankton show three adaptations to overcome the problem of the digestion of wax esters: an increase in the output of pancreatic lipase, elevated levels of non-specific lipases and esterases, and increased retention time of food due to the development of special morphological features such as pyloric caeca. The pyloric caeca appear to be amongst the most important sites for chitin digestion. The pyloric caeca are blind alleys in which digestion of food occurs slowly. On the other hand, there will be a few, if any, of undigested remains it will be returned to the intestine. The pyloric caeca and the duodenum are structurally similar with the same function in digestion. Furthermore, the distribution of goblet cells in the pyloric caeca was similar to the duodenum and jejunum. Pyloric caeca in large fish are resembled to the duodenum and presenting a number of folds increasing the absorptive secretary surface as a food reservoir (Figure 4.17). This area is important for lipid absorption (Morrison, 1987).

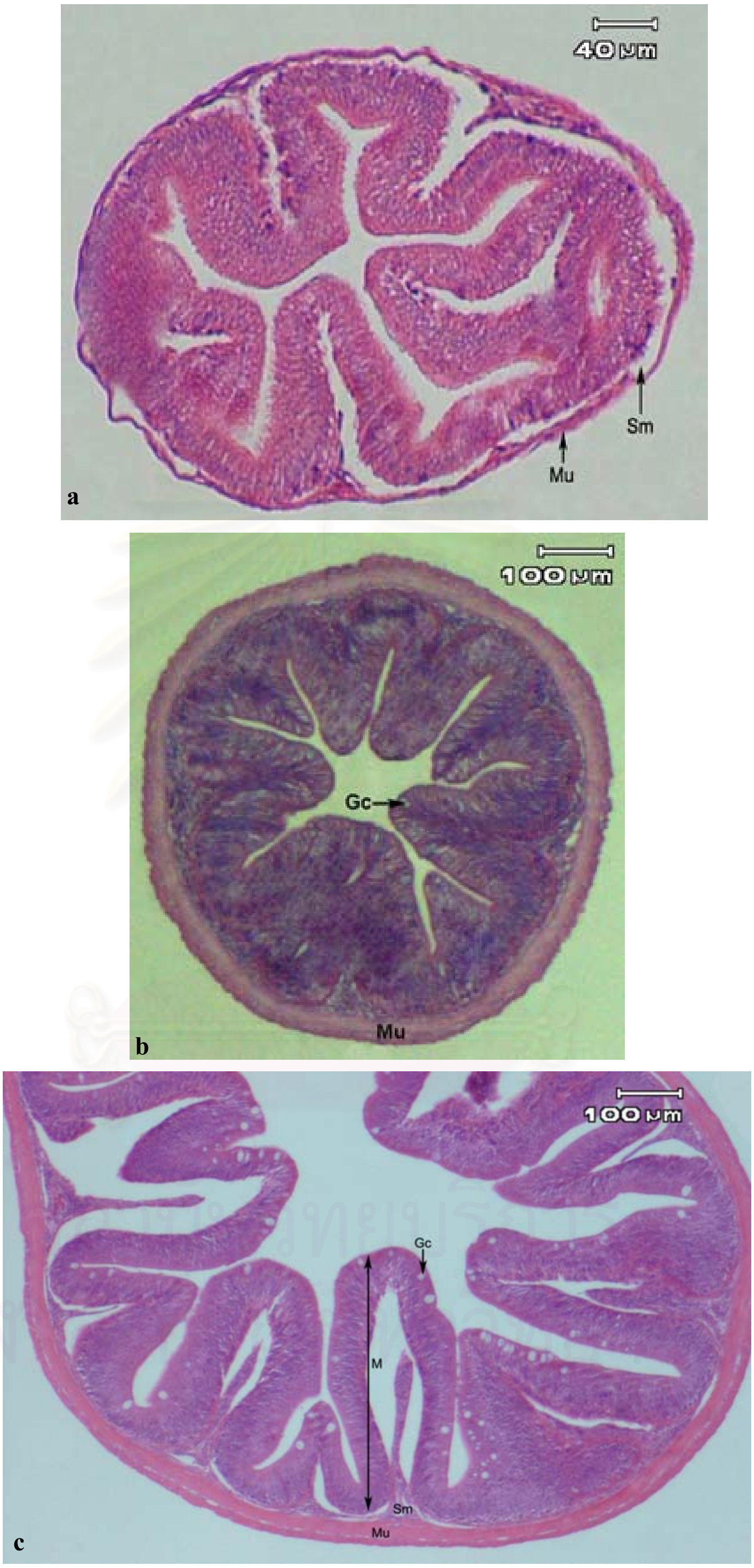



Figure 4.17 Pyloric caeca of larvae (a), juveniles (b) and adults(c) of spotted scat; Mu=Muscularis, Sm=Submucosa, M=Mucosa, Gc=Goblet cells; H&E.

**1.4 Intestine**

The intestine composed of duodenum, jejunum and ileum. Each stage of spotted scat has villi on the intestinal walls markedly increase in the duodenum as the main absorptive site. The lamina propria and submucosa are areolar connective tissue. The average of mucosa and muscularis layer of duodenum portion of three stages presented significantly difference ($p<0.05$) (Table 4.1, Figure 4.18 and Figure 4.20). The bile duct from the liver and gall bladder with enzymes from the pancreas is all flew into the duodenum portion. The goblet cells are found in a large number in duodenum while jejunum has branch fold for a large surface area for adsorption. The submucosa is composed of thick. The average of mucosa and muscular layer in jejunum portion of three stage showed significantly difference ($p<0.05$) (Table 4.1, Figure 4.19 and Figure 4.21).

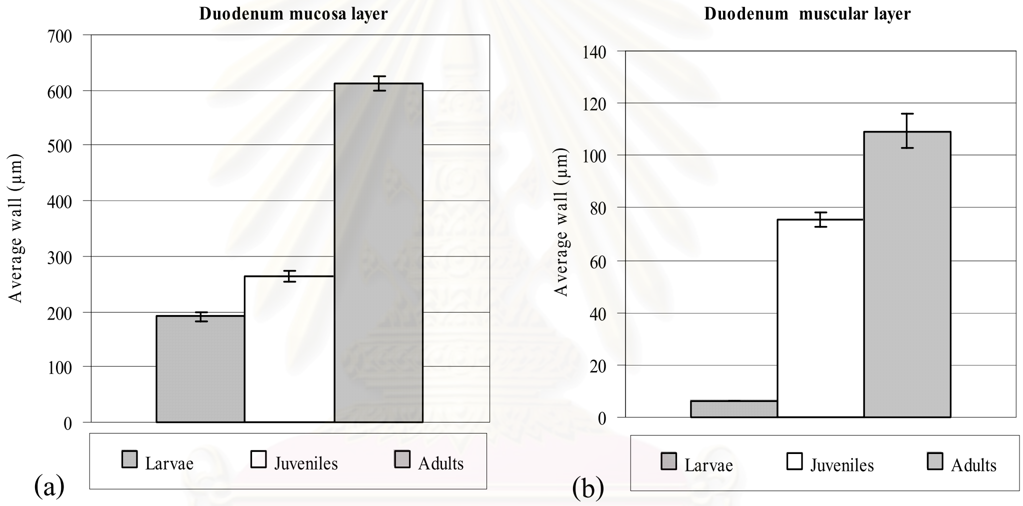



Figure 4.18 The thickness of mucosa (a) and muscular (b) layers in duodenum portion of spotted scat (Mean±SE) (n=5)

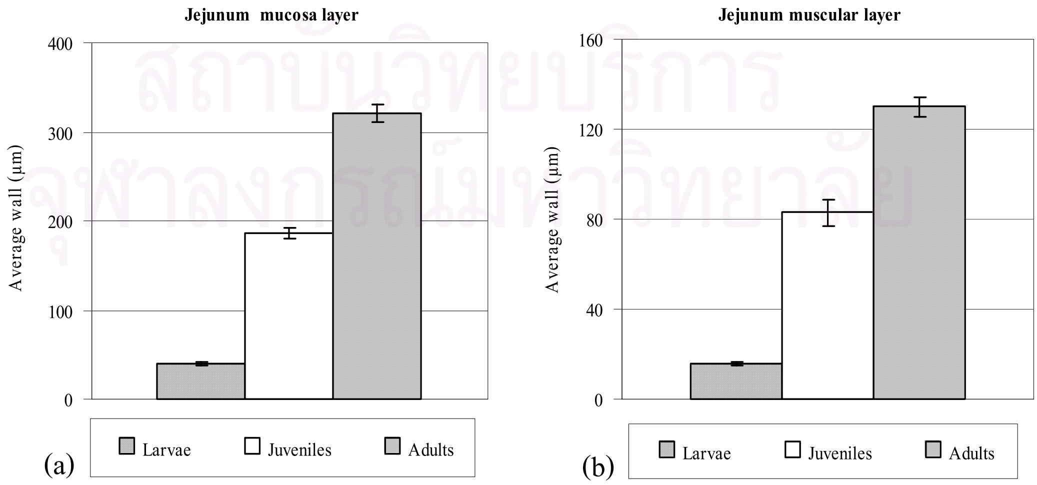



Figure 4.19 The thickness of mucosa (a) and muscular (b) layers in jejunum portion of spotted scat (Mean±SE) (n=5)

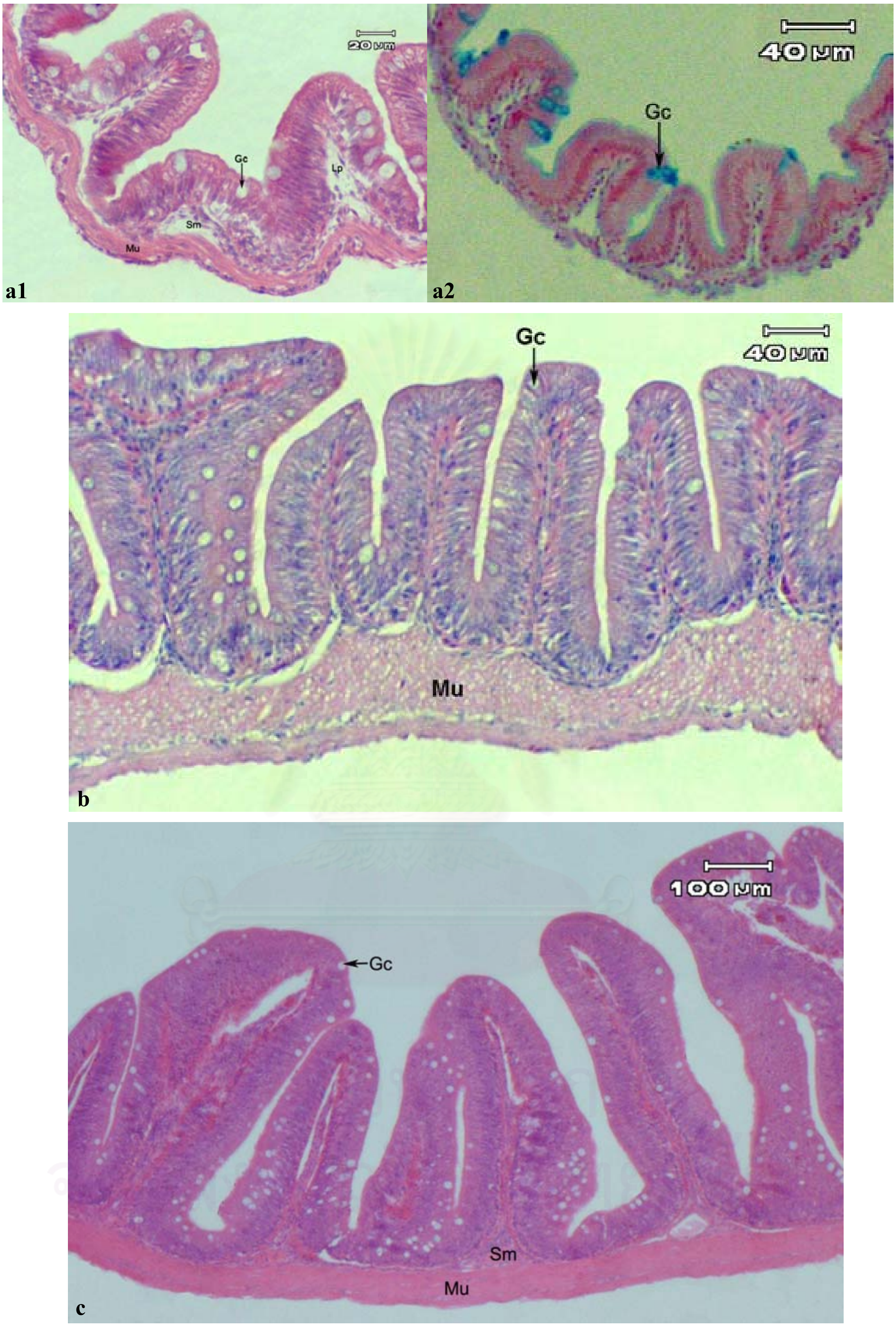



Figure 4.20 Duodenum portion of larvae (a1:H&E; a2:Alcian Blue), juveniles (b) and adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, Lp=Laminar propria, Gc=Goblet cells; H&E.

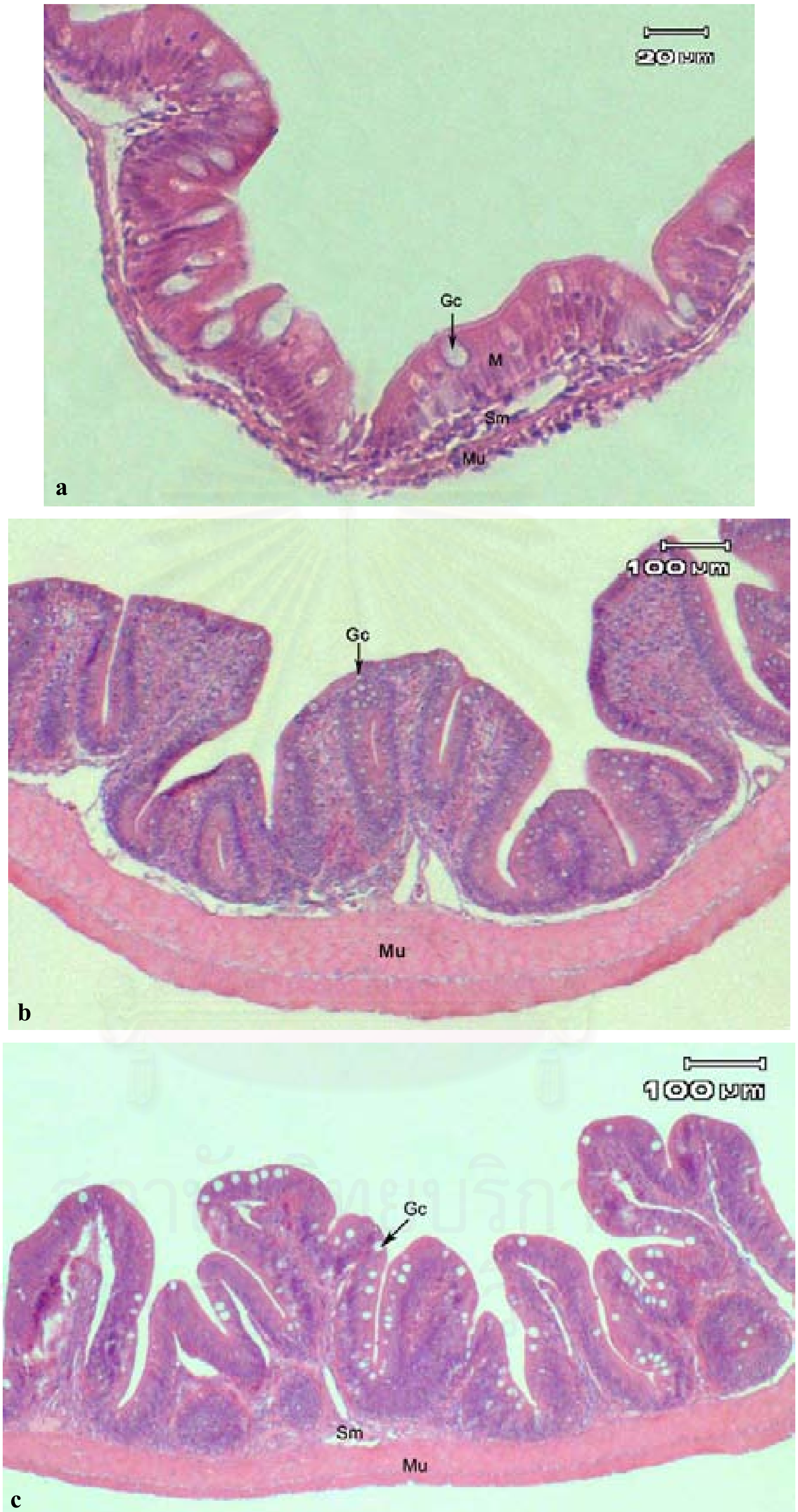



Figure 4.21 Jejunum portion of larvae (a), juveniles (b) and adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, M=Mucosa, Gc=Goblet cells; H&E.

Most of the enzymatic digestion of the foodstuffs occurs in the intestine. The enzymes responsible for digestion within the intestine may come from one of two endogenous sources. The pancreas secreted the greater varieties and quantities of enzymes. These exogenous enzymes will aid in the breakdown of food particles and nutrient into an absorbable form. In fish, the pancreatic tissue is dispersed in the region between the pyloric caeca and intestine. The secretions are produced and released by the pancreas, containing both digestive enzymes and bicarbonate, the latter acting to neutralize the gastric acid. Neutralization of the acidic gastric chyme is also aided by the secretion of bile from the gall bladder. The activity of pancreatic enzymes (trypsin, lipases and amylase) has been biochemically detected at first feeding and even before the mouth opening in many marine fish (Yúfera and Darias, 2007). Cytosolic enzymes of the enterocyte (amino peptidases, acid and alkaline phosphatases and esterases) are also presented.

The amylase activities in the guts of omnivorous and herbivorous species tend to be higher than those in the guts of carnivores. Proteolytic enzyme activity also appears to be correlated with feeding habits and relative the intestinal length. Carnivorous species, with the shortest guts, tend to have high pepsin levels, but low activities of pancreatic proteases. Herbivorous, detritivorous and microphagous species have relatively long guts, and relatively high levels of trypsin and chymotrypsin, but peptic enzyme activity may be low or absent. Omnivorous species take an intermediate position. Fish that consume insects and other animals with chitinous exoskeleton have high levels of intestinal chitinases, and those that consume planktonic copepods tend to produce relatively large amount of lipases, esterases and non-specific lipase. Cellulase activity does not, however, it appear to be closely linked with the dietary habits.

Fat when administered either alone or in a mixed diet routinely gives digestibility values of 85-95% for fish (Cho and Kaushik, 1990). In spotted scat, food items both microphytoplankton and zooplankton have fat digestibility almost 100% in each stage correspond with many fish larvae are very sensitive to a deficiency of n-3 PUFAs (Watanabe *et al*., 1983). Thus, the composition and amounts of fatty acids in zooplanktonic food affects growth and survival because zooplankton are good source of essential fatty acids. For example, a lipid-soluble growth factor extracted from zooplankton was shown to be active for coregonid larvae (Rembold and Fluchter, 1988). While the ability to utilize carbohydrates differs among fish species. The freshwater fish use higher dietary levels than various marine species (Lovell, 1998). Tilapia, *O. mossambicus*, shows higher amylase activity when changed to a starch-rich diet. The related species, *O. niloticus*, shows a decrease in carbohydrate level in response to high dietary levels of starch (Kawai and Ikeda, 1972).

Ileum portion, the mucosa of each stage is similar to that of the duodenum but the folds are either short, the chief differences being a greater degree of folding that are shorter and closely packed also the main absorptive site. The average of mucosa and muscular layers of three stages showed significantly difference ($p<0.05$) (Table 4.1, Figure 4.22 and Figure 4.23). The lamina propria and submucosa are areolar connective tissue. There are several goblet cells. The secretion of the goblet cells provided lubrication for the luminal surfaces. The mucous cells are generally few. The ileum is the site of water absorption via columnar absorptive cells. Abundant lymphatic tissue is commonly found in the lamina propria.

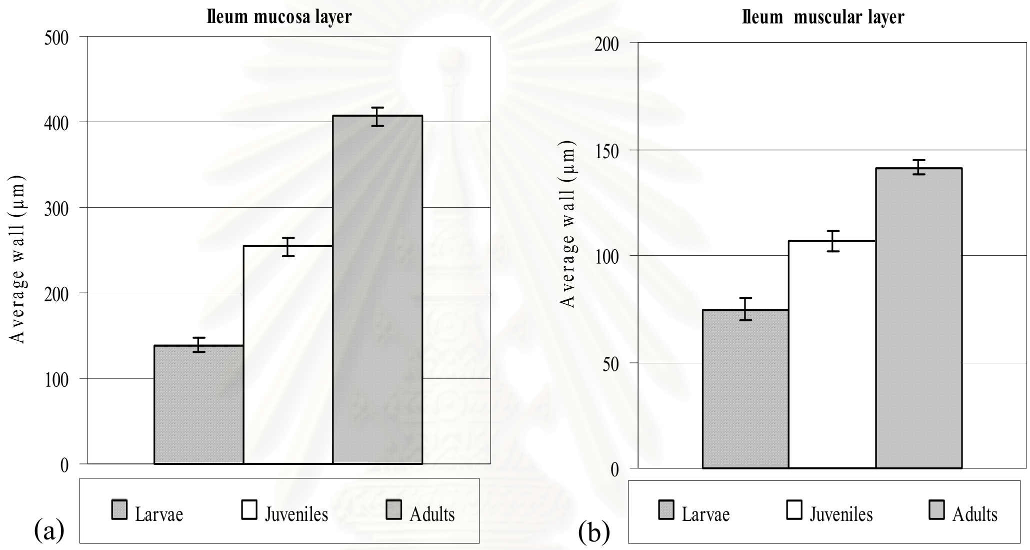



Figure 4.22 The thickness of mucosa (a) and muscular (b) layers in ileum portion of spotted scat (Mean±SE)(n=5)

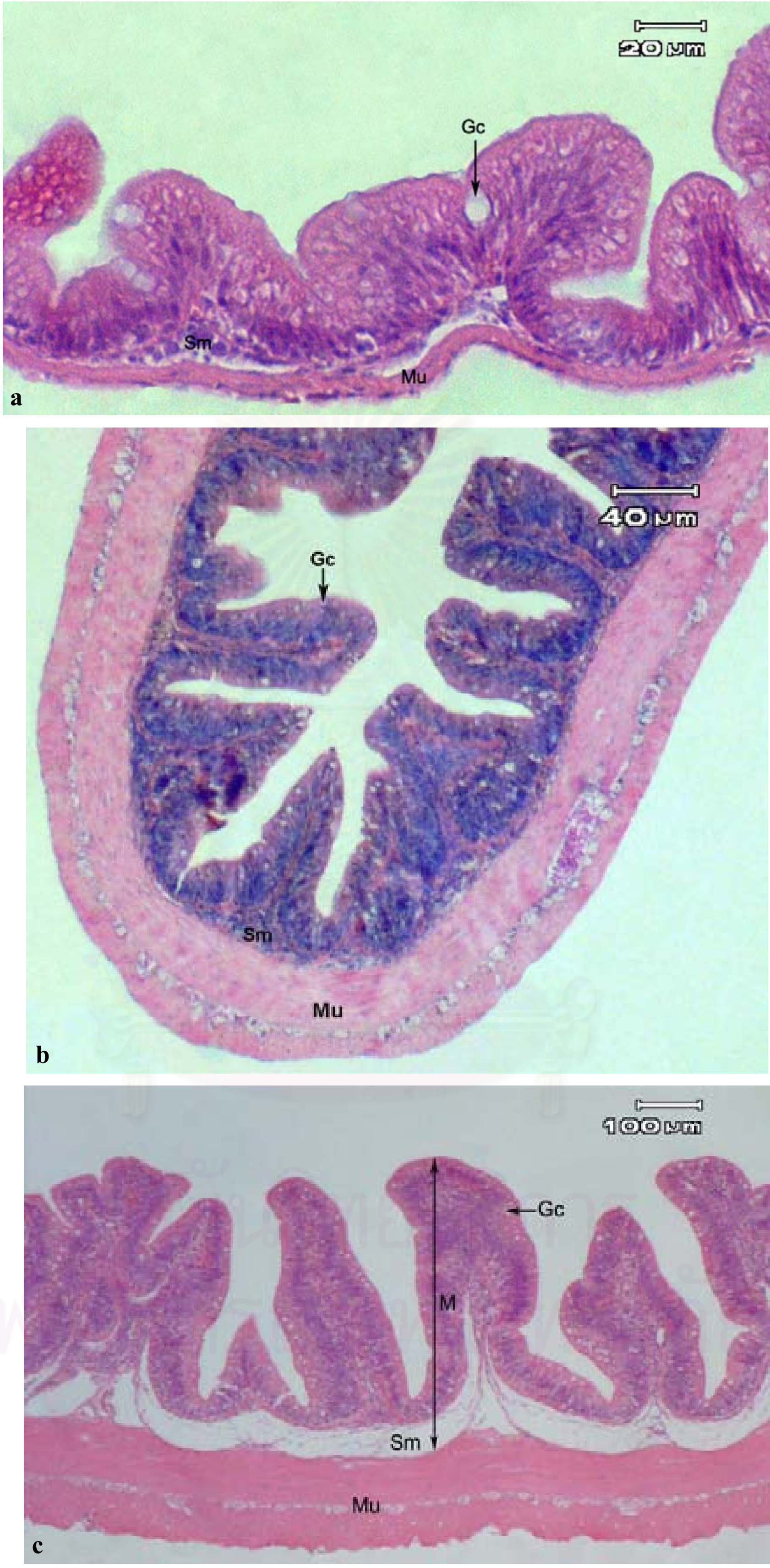



Figure 4.23 Ileum portion of larvae (a), juveniles (b) and adults (c) of spotted scat; Mu=Muscularis, Sm=Submucosa, M=Mucosa, Gc=Goblet cells; H&E.

**1.5 Liver**

Liver is located anteriorly to the stomach. The liver has both digestive and storage functions. Liver produced bile, a solution which emulsifies fats and may assist in changing the acidic conditions of the stomach into the neutral pH of the intestine (Lagler *et al*., 1962). It assists in digestion by secreting enzymes that break down fats, and also serves as a storage area for fats and carbohydrates. Bile is produced in the liver and the bile is usually stored in the gall bladder. The bile is produced more or less continuously, but is only secreted in large amounts in response to the presence of material in the intestine. The liver is also important in the destruction of old blood cells and maintaining proper blood chemistry, as well as playing a role in nitrogen excretion (Smutna *et al*., 2002).

The combined hepatic and pancreatic tissue are called hepatopancreas (Takashima and Hibiya, 1995). The liver is composed of a parenchyma covered by a thin capsule of connective tissue. It is divided into irregular lobules by the exocrine pancreas or hepatopancreas, associated to connective tissue. Within the parenchyma, the hepatocytes are radially arranged in cords around a central sinusoid. Large cells resting on luminal surface of the sinusoid endothelium are presented, these cells are known as Kupffer cells. Sinusoids are covered by typical endothelial cells with flatten nucleus. With argentic impregnation, a mesh a reticular fiber between the sinusoids and the trabecules of hepatocytes was observed. Hepatocytes shapes vary from polyhedral to round shape. Each hepatocyte contains a centrally round large nucleus with a prominent dark nucleolus. Veins are scattered through the liver parenchyma without a well-defined arrangement, and they are surrounded by hepatic parenchyma or pancreatic tissue, sometimes, accompanied by an artery or a bile duct. The main stored substances in liver cells are glycogen and lipids. With PAS reaction, large and rosette-shaped glycogen deposits were identified throughout the cellular parenchyma (Figure 4.24).

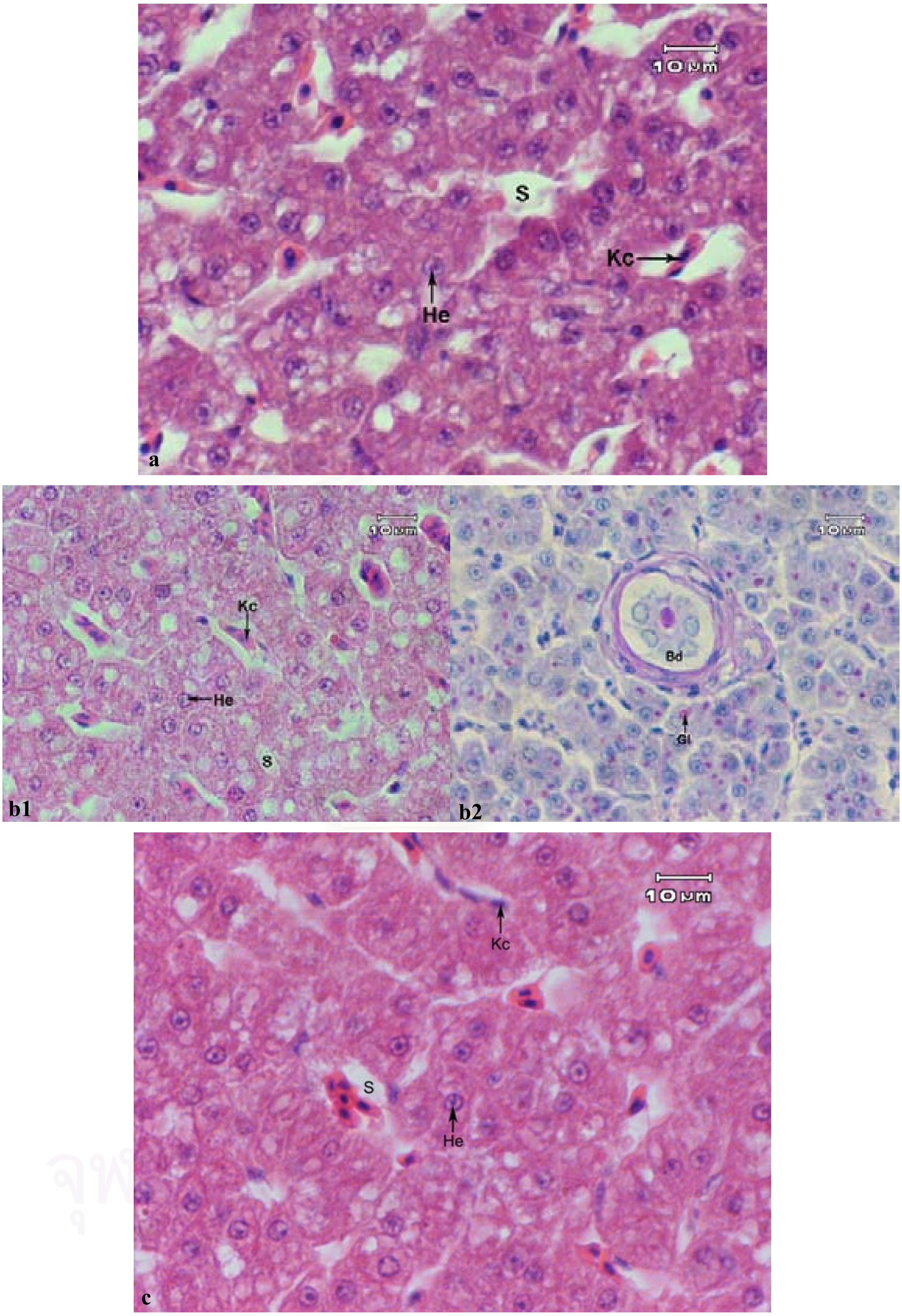



Figure 4.24 Liver of larvae (a), juveniles and glycogen granules revealed positively to a PAS stain (b1:H&E; b2:PAS) and adults (c) of spotted scat; S=Sinusoids, He=Hepatocytes, Kc=Kupffer cell, Gl=Glycogen granule, Bd=Bile duct; H&E.

**1.6 Pancreas**

At the larval stage, the pancreas and liver are morphologically independent without forming a hepatopancreas, even in fish with a diffuse pancreas. The pancreas of carnivorous fish synthesizes and secretes less amylase than the pancreas of herbivorous and omnivorous fish (David, 1971; Plisetskaya, 1989).

The pancreatic tissue was distributed along the venous system to the liver from stomach, pyloric appendages and intestine as well as pancreatic tissue is spreaded over the mesenteric fat (adipose tissue) surrounding the liver and the intestinal regions. The pancreas makes pancreatic juices and hormones. Pancreases are also found around major blood vessels. The pancreatic juices are enzymes that help digest food in the small intestine. They flow into the main pancreatic duct. This duct joins to the common bile duct, which connects the pancreas to the liver and the gallbladder. The common bile duct, a fluid that helps digest fat, connects to the small intestine near the stomach. The pancreas is thus a compound gland that it is composed of both exocrine and endocrine tissues. The exocrine function of the pancreas involves the synthesis and secretion of pancreatic juices. Exocrine pancreatic tissue is composed of a compound acinus gland (acinar cells) which numerous glandular cells are clustered. The cytoplasm of the glandular cells is strongly basophilic, providing a sharp contrast with the round, intensively acidophilic zymogen granules and therefore stains purple with hematoxylin and eosin. The endocrine function resides in the million or so cellular islands, the islets of Langerhans, embedded between the exocrine units of the pancreas. The islets of Langerhans secrete hormones including insulin and glucagons (Figure 4.25 and Figure 4.26).

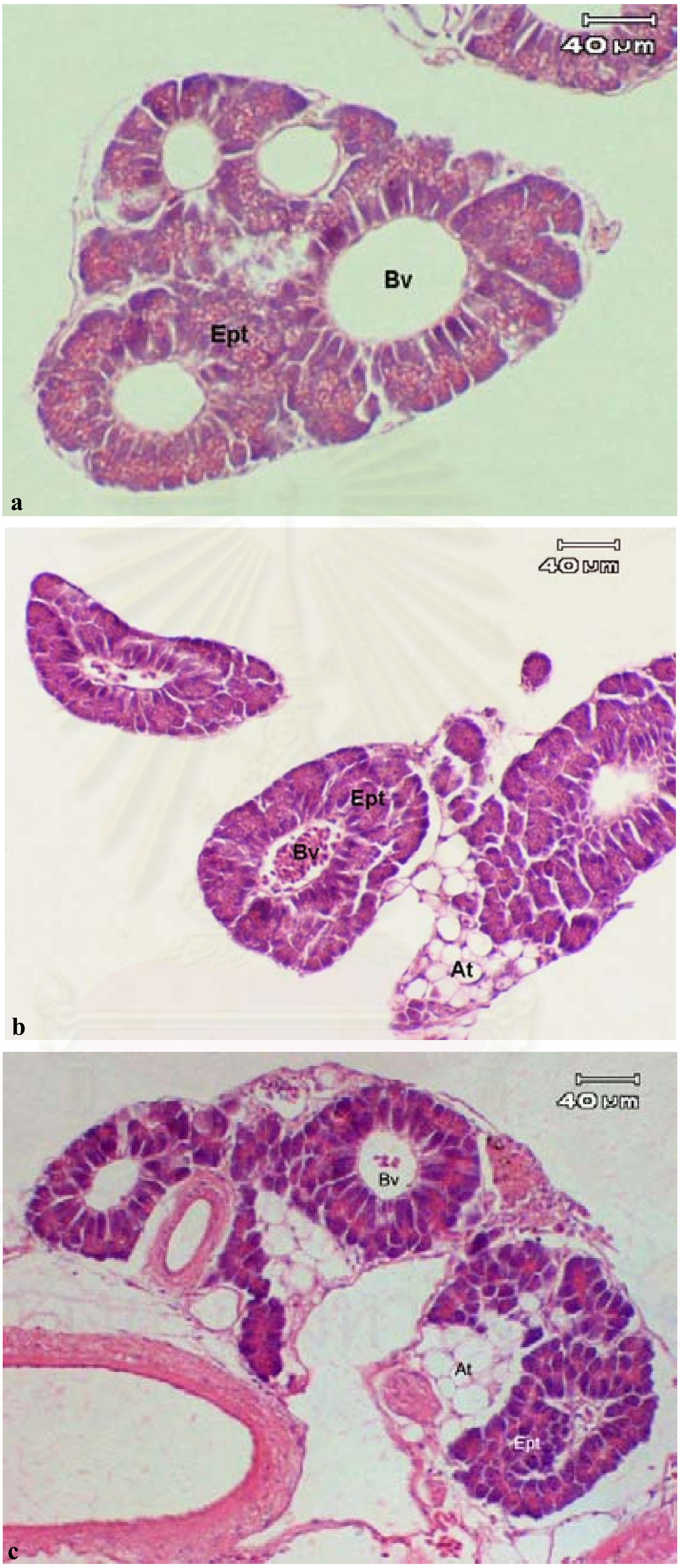



Figure 4.25 Pancreas of larvae (a), juveniles (b) and adults (c) of spotted scat; Bv=Blood vessel, Ept=Exocrine pancreatic tissue, At=Adipose tissue; H&E.

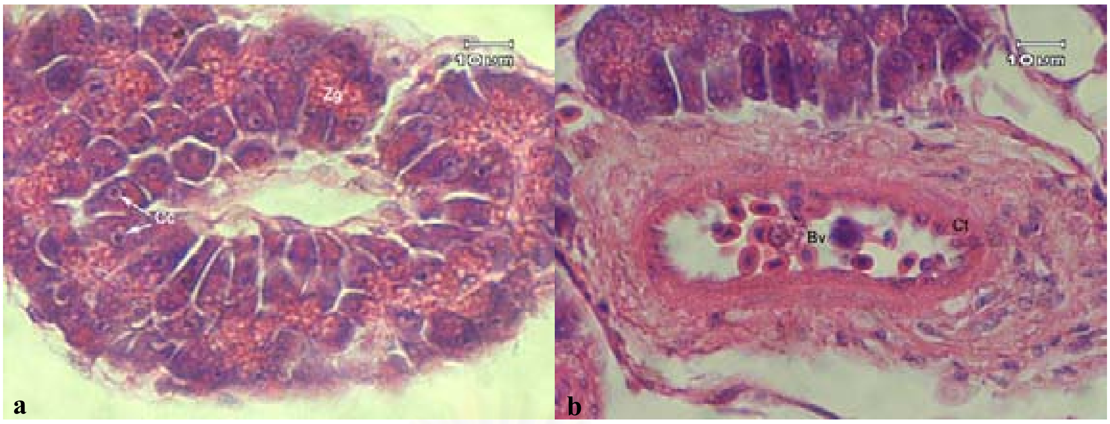



Figure 4.26 Acinar cells of pancreas (a) and connective tissue of a large blood vessel in mesentery (b) of juveniles spotted scat; Cc=Centroacinar cells, Zg=Zymogen granules, Bv=Blood vessel, Ct=Connective tissue; H&E.

**1.7 Gall bladder**

The gall bladder is blind sac, pear-shaped diverticulum of the common bile duct. The wall consists of the following layers: a mucosa composed of simple columnar epithelium and lamina propria, smooth muscle layer, perimuscular connective tissue and serous membrance. The submucosa layer is inner to the muscular layer, which consists of interlacing bundles of smooth muscle cells, the serosa is layer of loose connective tissue and simple flat epithelium. The common bile duct carries the bile stored in the gall bladder to the intestine (Figure 4.27).

The gall bladder and the liver play an important role in digestion. Bile accumulates in the gall bladder, and the bladder will gradually increase in size when fish was starved. During storage in the gall bladder, the bile may become more concentrated due to the absorption of water, the resulting may contain relatively large quantities of specific bile salt components accumulation. The presence of food in the intestine results in the bile flow from the gall bladder into the uppermost region of the intestine along the bile duct. Bile serves as a number of functions that helps emulsification, absorption of lipids/fats and neutralizes hydrochloric acid from stomach.

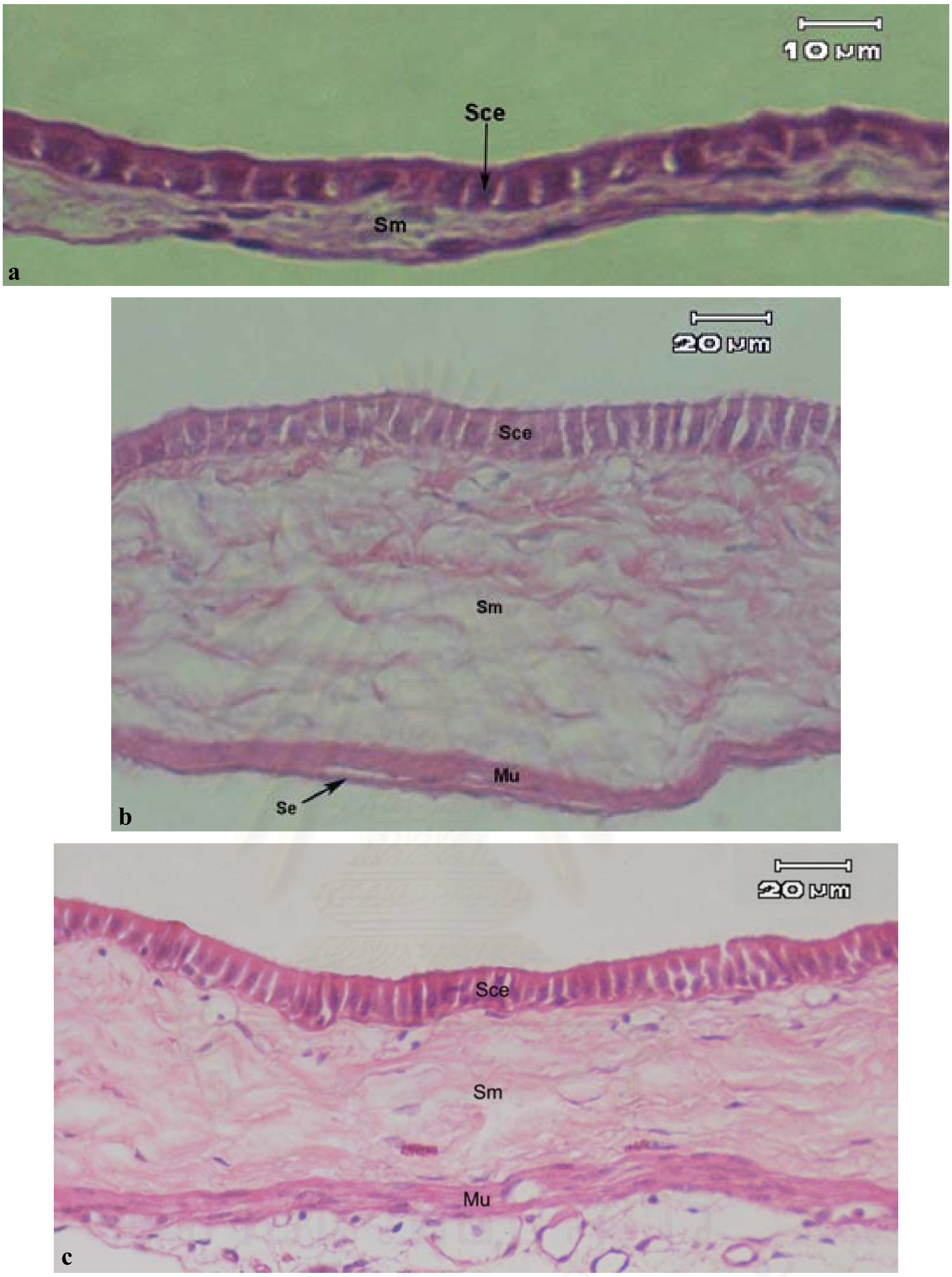



Figure 4.27 Gall bladder of larvae (a), juveniles (b) and adults (c) of spotted scat; Se=Serosa, Mu=Muscularis, Sm=Submucosa, Sce=Simple columnar epithelium and laminar propria; H&E.

**2. Digestion Efficiency**

The proximate analysis namely %Dry matter, %Ash, % Crude protein, %Crude fat and %Fiber of *Skeletonema* sp., *Chaetoceros* sp. and rotifer from feces of spotted scat are shown in Table 4.2. Crude protein percentage form rotifers have 59.26 % protein which higher than *Skeletonema* sp. and *Chaetoceros* sp. The protein level in rotifers has been reported to be in the range of 28 to 67% of dry weight, whereas no difference in the amino acid profile of rotifers which were fed different diets has been reported. Furthermore, the amino acid profile of rotifer does not deviate significantly from that of natural zooplankton or other cultivated zooplankton species (Lubzens *et al*., 1989).

Digestibility of crude protein of *Skeletonema* sp. food items in larvae was 88.79%, 72.52% in juveniles and 79.03% in adults. High digestibility of crude protein of *Chaetoceros* sp. in larvae was 95.02%, 81.78% and 86.31% in juveniles and adults respective. Digestibility of crude protein of rotifer was 90.62% and 88.98% in juveniles and adults respectively. From the results, protein digestibility of larvae was higher than that in juveniles and adults. Crude protein percentage from *Chaetoceros* sp. was the highest digestible by larvae while rotifers were digestible by juveniles and adults. These results corresponded with the digestion coefficients for protein in fish are usually in the range of 75-95 % (National Research Council, 1993). Moreover protein digestibility tends to be increased as the concentration of dietary carbohydrate depressed due to fiber digestion does not play an important role in their nutrition (Lindsay and Harris, 1980). This result showed crude fiber percentage of three stages has less than crude protein and crude fiber percentage of larval feces has less than juvenile and adult feces. For example, protein digestibility was highest in feedstuffs with high protein content (>60%) and low fiber content (<2%) in red drum, *Sciaenops ocellatus* (Mcgoogan and Reigh, 1996). Dry matter percentage and energy was positively influenced by protein and lipid content of the ingredient and negatively influenced by crude fiber content (Mcgoogan and Reigh, 1996). The result showed correlated with dry matter percentage form feces of three stages decreased from prey items and adult feces from all food items were less in %dry matter than larvae and juveniles feces.

The digestibility of any food consumption by fish must be determined by the balance between energy gain from the food and the energy expending on digestion (Xie, 1999). Gross energy from *Skeletonema* sp. was 377.80 kcal/100g, 411.83 kcal/100g from *Chaetoceros* sp. and rotifers 500.09 kcal/100g. Generally, digestible energy requirements of fish range from 233 to 410 kcal/100g diet depending on species and dietary protein levels (National Research Council, 1993). Apparently digested energy (DE) was the highest in rotifer which digested by juveniles and adults. In microphytoplankton, *Chaetoceros* sp. was the highest digested in all stages of fish (Table 4.3).

Table 4.2 Proximate analysis from three stages of spotted scat (Association of Official Agricultural Chemists, 1990)

| Proximate analysis | %Dry Matter | % Crude Protein | %Crude fat | %Ash | %Fiber |
|---|---|---|---|---|---|
| *Skeletonema* sp. | 13.89 | 19.98 | 1.90 | 4.09 | 0.42 |
| Fecal value in Larvae (n>50) | 7.85 | 2.24 | - | 6.01 | 0.19 |
| Fecal value in Juveniles (n=20) | 7.90 | 5.49 | - | 7.13 | 4.58 |
| Fecal value in Adults (n=5) | 6.82 | 4.19 | - | 6.42 | 1.86 |
| *Chaetoceros* sp. | 5.28 | 28.70 | 2.22 | 8.08 | 0.90 |
| Fecal value in Larvae (n>50) | 8.47 | 1.43 | - | 5.06 | 0.55 |
| Fecal value in Juveniles (n=20) | 7.94 | 5.23 | - | 6.12 | 2.40 |
| Fecal value in Adults (n=5) | 4.89 | 3.93 | - | 7.18 | 2.16 |
| Rotifer | 5.82 | 59.26 | 10.77 | 8.53 | 0.93 |
| Fecal value in Juveniles (n=20) | 8.00 | 5.56 | 0.88 | 6.33 | 5.50 |
| Fecal value in Adults (n=5) | 5.07 | 6.53 | - | 8.17 | 7.57 |

Table 4.3 Gross energy and apparently digested energy of prey items and feces (National Research Council, 1993)

| Food items/Feces | Gross Energy (kcal/100g) | DE (kcal/100g) (ADC of energy (%)) |
|---|---|---|
| *Skeletonema* sp. | 377.80 | |
| Feces in Larvae (n>50) | 357.46 | 20.34(5.38%) |
| Feces in Juveniles (n=20) | 357.63 | 20.17(5.34%) |
| Feces in Adults (n=5) | 362.99 | 14.80(3.92%) |
| *Chaetoceros* sp. | 411.83 | |
| Feces in Larvae (n>50) | 357.58 | 54.25(13.17%) |
| Feces in Juveniles (n=20) | 361.22 | 50.52(12.29%) |
| Feces in Adults (n=5) | 367.41 | 44.43(10.79%) |
| Rotifer | 500.09 | |
| Feces in Juveniles (n=20) | 365.27 | 134.82(26.96%) |
| Feces in Adults (n=5) | 366.57 | 133.52(26.70%) |

However, the results of gross energy food items could conclude that spotted scat larvae have high protein absorption which corresponded to several researches as in the *Solea solea* larvae (Boulhic and Gabaudan, 1992). Protein absorption in *Scophthalmus maximus* larvae began on the first day of active feeding, while absorption of lipids occurred after 5-6 days. In fact, the use of microalgae seems to be essential during the first stage of common pandora larval rearing (Family Sparidae) as well as other marine larvae (such as *Sparus aurata*, *Pagrus pagrus*) (Klaoudatos *et al*., 2004). Microphytoplankton may act as a diet component and/or stimulating factor of digestive enzyme synthesis. Since the high levels of protein may lead to the consumption of protein for energy. Furthermore, proteins are very important in the growth of fish (Lovell, 1998). Wild omnivorous fish normally feed on abundant live organisms, rich in proteins which provide an abundant energy source (Moyle and Cech, 1982).

**3. Optimal Foraging Theory (OFT) in Spotted Scat as Related to Energy/ Assimilation Efficiency**

The experimental result on digestion efficiency supported that spotted scat feeding followed optimal foraging theory in term of energy/assimilation efficiency. In larvae, *Chaetoceros* sp. was the most suitable diet. *Chaetoceros* sp. provided high crude protein 28.7%, crude fat 2.22% and gross energy 411.83 kcal/100g as feed for spotted scat. The energy digestibility of larvae was 54.25 kcal/100g (13.17%) gained from *Chaetoceros* sp. than those gained from *Skeletonema* sp. of 20.34 kcal/100g (5.38%). Several studies have demonstrated that fish larvae have very high growth rates as compared to adult stages (RØnnestad *et al*., 2003). In addition to the protein deposition, amino acids are a major energy during the early life stages of several marine teleost species (Parra *et al*., 1999; RØnnestad *et al*., 1999). The ash, protein, fat and carbohydrate content determinations indicate a high food quality of diatoms. It could be concluded that diatom as reliable food source of high nutritional quality for fish (Romer and McLachlan, 1986).

Juvenile and adult spotted scat have the highest apparently digested energy from rotifer. Juveniles have apparently digested energy 134.82 kcal/100g (26.96%) and 133.52 kcal/100g (26.70%) in adults, low digested energy from *Chaetoceros* sp. and *Skeletonema* sp. were observed. Based on the digestion efficiency, juvenile and adult spotted scat most likely preferred rotifers with higher proximal content (crude protein 59.26%, crude fat 10.77%) and higher gross energy 500.09 kcal/100g than microphytoplankton. The presence of a food item in a diet depends on its availability, its detection by the fish and its selection as food. Selection may depend on the mechanical ability of the fish and profitability of the prey (Wootton, 1999). Spotted scat can select diets on the basis of at high nutritional and energy value to obtain prey profitability. The optimal food particle size expected to change during ontogenetic development. Prey sizes are often found to select close to the optimum in size.

Furthermore, the stomach content of juvenile and adult spotted scat from Pak Phanang Estuary were predominantly microphytoplankton which correlated to the feeding preference experiment. Juveniles preferred *Chaetoceros* sp., *Skeletonema* sp. and rotifers respectively. *Chaetocreos* sp. in the preference experiments were first selected as compared to rotifers due to their high density (3,845 cells/ml). Single cell microphytoplankton (6-24 μm) matched the mouth gape as optimal prey size. Energy value was also high. Therefore, if two different preys were available, the forager would choose the nutritionally favorable prey. The availability of the prey to predators depend not only its population density, but also its activity, exposure and defence mechanisms (Vinyard, 1980). Selection of food in juveniles was based on the optimal prey size and high density prey.

Adult spotted scat in the preference experiment selected *Skeletonema* sp., *Chaetoceros* sp. and rotifers respectively. *Skeletonema* sp. was selected due to the long chain morphology which was easy to encounter and catch. Furthermore, the densities *Skeletonema* sp. in the tank was also high as in *Chaetoceros* sp. Densities of *Skeletonema* sp. were 6,460 cells/ml meanwhile *Chaetoceros* sp. 1,954 cells/ml and rotifer 4 individuals/ml. Adult spotted scat are flexible in their choice of foods responding to changes in the availability or profitability of potential preys. Therefore, when adult spotted scat encounter preys at random, the diet selection depends on the density of the more profitable items. From the obtained results, *Skeletonema* sp. was selected first. Thus the adult spotted scat clearly showed their feeding following the optimal foraging theory.

**4. Trophic Role of Spotted Scat in Mangrove Food Webs**

The trophic-cascade model incorporates the concepts of top-down and bottom-up control (Carpenter and Kitchell, 1993). The production and species composition in community are controlled by the abundance and species composition at the high trophic level such as piscivore, benthic feeder, zooplankton feeder and omnivore. This is called top-down control. On the other hand, the correlations between overall production and the amount of primary production namely picoplantkon, nanoplankton, microphytoplankon and detritus suggest that abiotic factors, especially temperature, nutrient and light will be the most important controlling factors through their effects on food availability as bottom-up control. Both effects may occur simultaneously and that their relative importance varies with the system and over space and time.

In Pak Phanang mangrove food web, the variation in primary production namely microphytoplankon and detritus showed bottom-up control. While top-down controls were piscivorous fish, birds and reptiles, feeding on zooplankton feeder, benthic feeders and omnivorous fish. These fish in turn affected the abundance of macrozooplankton and macrobenthos. Herbivorous and zooplankton feeder with high grazing rates also affected the biomass of microphytoplankon. When piscivores and other top carnivores absent, the zooplankton feeders, benthic feeders and omnivorous fish, by their size-selective feeding, may eliminate the large zooplankton species. This may increase biomass of mirophytoplankton.

Spotted scat were omnivore and classified as the secondary consumer in mangrove food webs in Pak Phanang Estuary during high and low salinity period. The trophic role of spotted scat in the mangrove food webs were in the same level with zooplankton feeders and benthic feeders. Moreover spotted scat showed the top-down controls on microphytoplankton, detritus, zooplankton and benthos. Spotted scat abundance and biomass served as the prey item for top carnivore such as pisivores such as *Plotosus canius*, *Arius acutirostris*, birds and reptiles. Piscivorous fish and birds mostly consumed spotted scat in larval stage. Reptiles consumed both juvenile and adult spotted scat.

During low salinity period, Cyanophyceae namely *Anabaena* spp., *Oscillatoria* spp. *Anabaenopsis* spp., diatoms, *Nitzschia* spp., and detritus were dominant. These were the main prey items of spotted scat. Microzooplankton, macrozooplankton such as copepods, rotifers, zoea of brachyuran, cirripede nauplii, bivalve larvae, gastropod larvae including microbenthos and macrobenthos such as nematodes, polychaetes and tanaidaceans were also prey items of spotted scat (Figure 4.28).

In the high salinity periods, spotted scat feed mainly on diatoms namely *Nitzschia* spp., *Skeletonema* sp., *Pleurosigma/Gyrosigma* spp. and *Surirella* spp. Detritus, zooplankton including copepods, ostracods, zoea of brachyuran, cirripede nauplii, mysids, gastropod larvae, bivalve larvae and benthos such as nematodes, polychaetes, amphipods, isopods, insect larvae, tanaidaceans and foraminiferan were also found. (Figure 4.29). From the food web during low and high salinity period in Pak Phanang mangrove forests showed that spotted scat have flexibility in term of feeding adaptation. Their flexibility in feeding were not limited to prey items. They are able to switch to other foods if it is necessary or advantageous. Thus, spotted scat were opportunist feeders and could switch their prey items accordingly to the environmental changes. Being omnivore, their diets ranged from microphytoplankton, protozoans, zooplankton, benthos and detritus. They switch from one type of prey to another as the relative amount of the prey types changes. During the low salinity period, adult spotted scat predominantly feed on *Zoothamnium* spp. The diets during high salinity period were more diversed. Ontogenetic change in this fish was evidenced. In larval stage, they predominantly feed on microphytoplankton in the water column. Juvenile fish, transitional stage feeding both in water column and mangrove floor, feed on resuspended benthic diatom, zooplankton, benthos and detritus. Adults, feeding mainly in the midwater level and mangrove floor, with most diversed prey items ranging from microphytoplankton, protozoans, zooplankton, benthos and detritus. The latter two prey items greatly increased in adult diets. The feeding preference and digestion efficiency further supported that spotted scat feeding followed the Optimal foraging theory. *Chaetoceros* sp. is the reliable food source of high nutritional quality for larvae. *Chaetoceros* sp. provided high crude protein 28.7%, crude fat 2.22% and gross energy 411.83 kcal/100g as feed for spotted scat. The energy digestibility of larvae was 54.25 kcal/100g gained from *Chaetoceros* sp. than those gained from *Skeletonema* sp. of 20.34 kcal/100g. Juveniles have apparently digested energy 134.82 kcal/100g and 133.52 kcal/100g in adults, low digested energy from *Chaetoceros* sp. and *Skeletonema* sp. were observed. Based on the digestion efficiency, juvenile and adult spotted scat most likely preferred rotifers with higher proximal content than microphytoplankton. Selection of food in juveniles as revealed from the feeding preference experiments, it based on the optimal prey size, *Chaetoceros* sp. and high density prey. Diet selection in adult spotted scat depends on the density of the more profitable prey. *Skeletonema* sp. was the first choice. *Chaetoceros* sp. and rotifers were chosen next. This characteristic is the important advantage in terms of both survival and mobility in estuary.

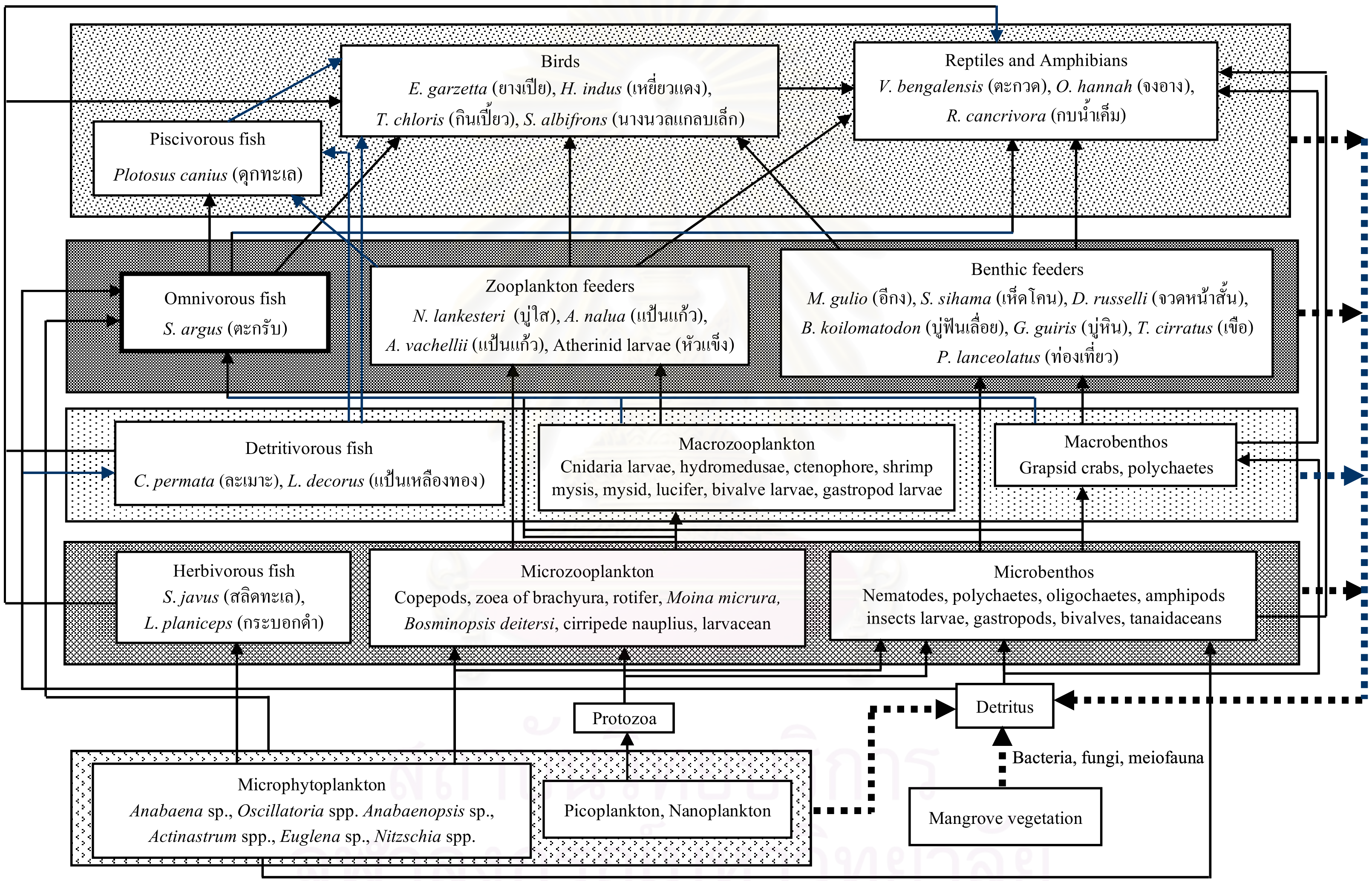


Figure 4.28 The trophic level of spotted scat in mangrove forest food web, Pak Phanang Estuary during low salinity period

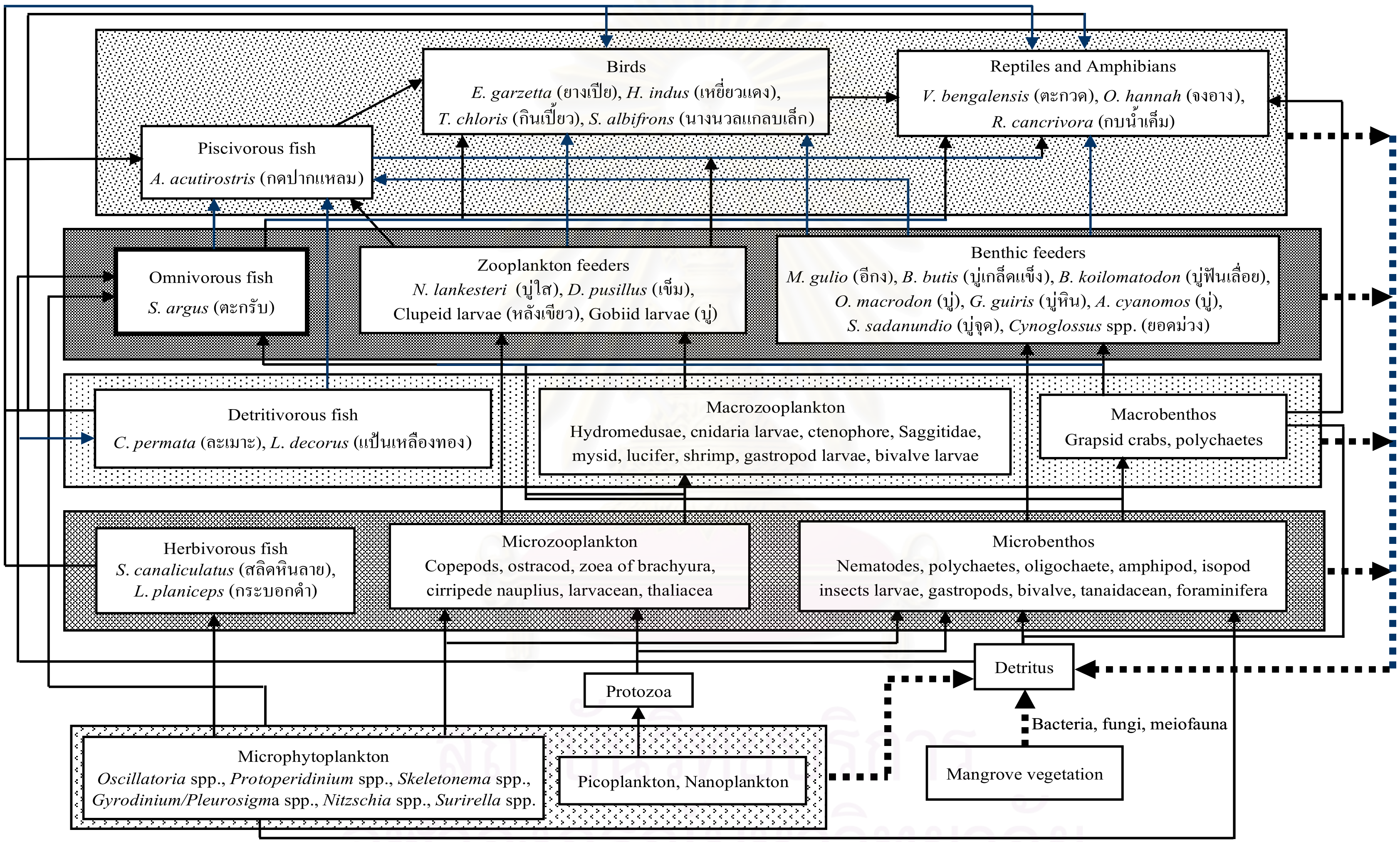



Figure 4.29 The trophic level of spotted scat in mangrove forest food web, Pak Phanang Estuary during high salinity period

## E. Conclusion

### 1. Histological Adaptation in Spotted Scat as Related to Food Spectra and Feeding Behavior

The histology of digestive system in *Scatophagus argus* showed a relationship with food spectra and feeding behavior. The dominant prey items of spotted scat are microphytoplankton, protozoans, zooplankton, benthos and detritus to be consistent with Arrunyagasemsuke (1975); Boonruang *et al.* (1994); Vitheesawat, (1999); Musikasung *et al.* (2006); Wongchinvit *et al.* (2006). The development of digestive system, beginning from mouth parts confirmed that spotted scat are mainly benthic omnivore. They showed flexibility to switch from one type of prey to another as the relative amount of the prey types changes. Diets during high salinity period were more diversed. Ontogenetic change in spotted scat was evidenced. The ontogenetic differences in feeding habits have resulted from acquiring high energy diets to accompany growth and changes in the morphology of feeding structure and digestive system. The feeding preference and digestion efficiency further supported that spotted scat feeding also followed the optimal foraging theory.

The significance of the digestive tract development changes relate to morphological structure and feeding behavior of fish, especially in larval stage that low locomotory and perceptual capability. Larval development, teeth appear on the jaws distinctly, oral cavity has taste buds for fish in controlling food intake which specific features of distribution and the number of taste buds in each taste zone correlate with specific features of the feeding and feeding behavior. Villiform teeth appear on the maxilla and mandible in all sizes. Ciliiform teeth also appear on tongue in juvenile and adult. Larval teeth used for grasping rather than masticating microphytoplankton and small zooplankton as main food items. In a larger fish, teeth are high in number and all of them have the same form but different sizes. They used for grinding large zooplankton and benthos beside microphytoplankton. The esophageal mucosa shows stratified epithelium and contains of mucous cells aiding in the passage of food.

The stomach of spotted scat was classified into three parts namely cardiac, fundic and pyloric portion. Cardiac portion have high in number of mucous secreting cells and goblet cells which lining to protect the mucosa against proteolytic degradation. The fundic portion has a number of gastric glands markedly increasing of which secreting gastric juices. Most of the food items such as pennate diatoms, *Oscillatoria* spp., *Zoothamnium* spp. and zooplankton were digested at this portion. The muscular layer thickness of the pyloric stomach is dramatically increased for moving food to intestine. The gastric glands were not observed in the pyloric part of the stomach. The junction of the stomach and the intestine is marked by the pyloric caeca. The caeca increase the area for digestion and absorption resemble a number of papillarous structure. The caeca form digestive compartments are active in resorption of fat. The fat from natural diet is predominant zooplankton such as calanoid copepods.

The intestine composed of duodenum, jejunum and ileum portion. The villi on the intestinal walls are markedly increased from duodenum to ileum as the main absorptive site. The goblet cells are found in a high number. In duodenum, the average thickness of mucosa layer is the highest among the jejunum and ileum while, jejunum has branch fold for increasing surface area for lipid and protein adsorption. The ileum is the site of water absorption via columnar absorptive cells. The other digestive organ namely pancreas, gall bladder and liver secreted digestive enzymes for fat digestion into the intestine and also hormones into the blood.

**2. Feeding in Spotted Scat Following Optimal Foraging Theory in Term of Assimilation Efficiency**

Stomach content of spotted scat as omnivore in Pak Phanang Estuary showed broad diets including microphytoplankton, protozoans, zooplankton, benthos and detritus. The development of feeding morphological structure namely mouth morphology, teeth, gill rakers and digestive tract were all related to allow this broad diet. Teeth on the jaw implied that the prey items must be easily captured and digested independently of these mechanisms. The short gill rakers were developed to collect and filter food. The large stomach showed the consumption of large volume of food. The pyloric caeca as an adaptation to increase the absorption surface, the nutrient uptake capacity of the gut and allowed to optimize digestion of diversed prey items. The experimental results from the feeding preference and digestion efficiency further supported that spotted scat feeding followed the optimal foraging theory. They are flexible in their choice of foods responding to changes in the availability or profitability of potential preys. *Chaetoceros* sp., diatom, is the reliable food source of high nutritional quality for larvae. Based on the digestion efficiency, juvenile and adult spotted scat most likely preferred rotifers with higher proximal content and gross energy than microphytoplankton. However selection of food in juveniles as revealed from the feeding preference experiments, it based on the optimal prey size, *Chaetoceros* sp. and high density prey. Diet selection in adult spotted scat depends on the density of the more profitable prey. *Skeletonema* sp. was the first choice and *Chaetoceros* sp. and rotifers were respectively.

**3. Trophic Ecology**

In Pak Phanang food web, spotted scat were omnivore, secondary consumer, and opportunist feeder. Spotted scat could classify in same level with zooplankton feeders and benthic feeders. The food web during low and high salinity period in Pak Phanang mangrove forests showed that spotted scat have flexibility in term of feeding adaptation. Their flexibility in feeding were not limited to prey items. They are able to switch to other foods if it is necessary or advantageous. Thus, spotted scat were opportunist feeders and could switch their prey items accordingly to the environmental changes. Spotted scat were omnivore and being trophic adaptability opportunistic feeder. Their diets ranged from microphytoplankton, protozoans, zooplankton, benthos and detritus. They switch from one type of prey to another as the relative amount of the prey types changes. Ontogenetic change in this fish was evidenced. In larval stage, they predominantly feed on microphytoplankton in the water column. Juvenile fish, transitional stage feeding both in water column and mangrove floor, feed on resuspended benthic diatom, zooplankton, benthos and detritus. Adults, feeding mainly in the midwater level and mangrove floor, with most diversed prey items ranging from microphytoplankton, protozoans, zooplankton, benthos and detritus. The latter two prey items greatly increased in adult diets. From the trophic level, top-down control by spotted scat, sorting out the ability of spotted scat not only control the abundance of microphytoplankton, detritus, zooplankton and benthos but they served as prey items for top carnivore namely piscivores such as *Plotosus canius* and *Arius acutirostris*, birds and reptiles. Piscivores and birds consumed spotted scat in larval stage and reptiles consumed juvenile and adult spotted scat.

# CHAPTER V

# NICHE PARTITIONING IN SPOTTED SCAT *Scatophagus argus* AND ADULT TADE MULLET *Liza planiceps* COMMUNITIES

## A. Introduction

Spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* are two co-occurring fish in Pak Phanang Estuary, Nakhon Si Thammarat Province (Somkleeb *et al*., 2001; Sritakon *et al*., 2003; Assava-aree, 2004; Paphavasit *et al*., 2004; Assava-aree and Sriaroon, 2005; Shinnaka *et al*., 2007). These fish utilized the mangrove forests and estuarine waterways as feeding grounds. Spotted scat, being omnivore, feed on the diversed food sources provided by the mangrove forest ranging from microphytoplankton, protozoan, zooplankton, benthos and detritus. Mullets have frequently been considered as herbivore, plankton feeder, omnivore, microcrustacean predator and detritivore (Odum, 1970; Fagade and Olaniyan, 1973; Blaber and Whitfield, 1977; Bruslé, 1981; Tammongkut, 1984; Leh and Sasekumar, 1991; Paphavasit *et al*., 2000; Laffaille *et al*., 2002; Almeida, 2003). The feeding plasticity of these species is reflected in the extensive terminology used by different authors to label the trophic behavior of mullets.

Niche partitioning in fish sharing the same feeding grounds may be the alternative process in reducing competition for the same resources. Niche partitioning may resulted in different feeding types, different components of diets utilized or different food sources in the same habitats whether in the pelagic or benthic origins. Differences in feeding structure morphology and time of feeding may also be the outcomes of niche partitioning. The study has been conducted on the niche partitioning in mangroves and coastal areas in fish of the same family namely mullets in the family Mugilidae (Tammongkut, 1984; Paphavasit *et al*., 2000). The objectives of this study are to assess the diets of these two occurring fish from stomach content analyses and determine the niche overlap in term of food sources. Niche partitioning between spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* is elucidate.

## B. Literature Review

### 1. Distribution of Two Co-Occurring Species in Pak Phanang Mangrove Forests

The scientific name "*Liza planiceps*" (Valenciennes, 1836) (Tade mullet), Harrison and Senou (1999) remarked in Carpenter and Niem (1999) *Liza planiceps* classified into

Phylum Chordata

Subphylum vertebrata

Class Actinopterygii

Subclass Neopterigii

Division Teleostei

Order Mugiliformes

Family Mugilidae

Genus *Liza*

Species *Liza planiceps* (Tade mullet)

*Liza planiceps* have frequent synonyms/misidentification such as *Mugil belanak* (Bleeker, 1875); *M. tade* (Forsskål, 1775); *Chelon tade* (Forsskål, 1775), *Liza tade* (Forsskål, 1775)/ *L. parsia* (Hamilton Buchanan, 1822); *L. subviridis* (Valenciennes, 1836); *L. vaigiensis* (Quoy and Garmard, 1825).

Diagnostic characters: Body elongate; head broad, depressed and pointed. Eye diameter 14 to 33% head length. Adipose eyefold developed covering up to 1 and 2 of iris. Anal fin with III spines and 9 soft rays. Caudal fin forked. Pectoral fins with I spine and 15 to 16 soft rays; short, not reaching origin of first dorsal fin; pectoral fins 16 to 20% standard length, 70 to 80% head length, less than length of head minus snout. Pelvic fins shorter than head minus snout. Ctenoid scale with 30 to 35 in longitudinal series; 10 or 11 in transverse series; 8 or 9 scales in longitudinal series anterior to tip of pectoral fins and 21 to 23 anterior to origin of second dorsal fin; 16 scales in transverse series entirely around caudal peduncle (Figure 5.1).



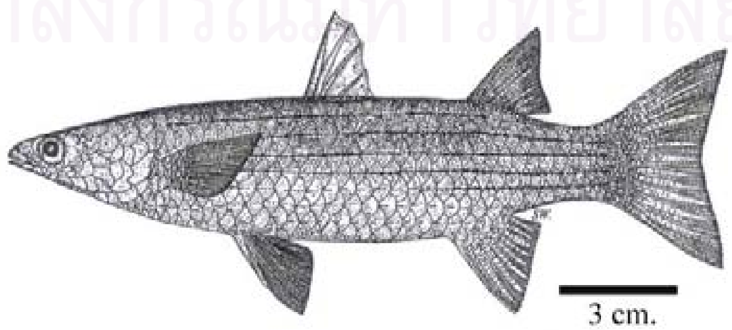



Figure 5.1 Morphological characters of *Liza planiceps* in total length 23 cm from this study

*Scatophagus argus*, spotted scat and *Liza planiceps*, tade mullet were co-occurring fish in Pak Phanang Estuary, Nakhon Si Thammarat Province. These fish utilized the mangrove forests and estuarine waterways as feeding grounds. The mullets usually are found in small groups or schools over shallow-water, often jump at surface. They usually swim over sandy-muddy bottoms. They can found chiefly marine coastal and brackish water, only some species occasionally swim far up river and a few species spend their entire adult lives in rivers. Sritakon *et al*. (2003), Assava-aree (2004) and Assava-aree and Sriaroon (2005) reported *Liza subviridis* and *Scatophagus argus* in Pak Phanang River and its tributary. *L. subviridis* were found in the upper reach of estuary in freshwater while *Scatophagus argus* widely distributed from Cha-Uat District to Pak Phanang Estuary. Salinity is the important factor affecting the distribution in mullets.

Somkleeb *et al*. (2001) reported that fish in the family Mugilidae, true residents, were abundant and widely distributed in the Pak Poon mangrove forest. This corresponded to report by Tongnunui *et al*. (2000) and Sikhantakassamit *et al*. (2001). In Pak Phanang mangrove plantations *Chelon macrolepis* and *C. tade* were abundant in both the day and night catches (Paphavasit *et al*., 2004). Shinnaka *et al*. (2007) studied on the effects of mangrove deforestation on fish assemblage at Pak Phanang Bay. Small *Scatophagus argus* were most abundant species in the mangrove forest than the degraded forest area. Small *Chelon subviridis* was found in the degraded area.

**2. Feeding Types in Adult Mullet**

Mullets have frequently been considered as herbivorous, omnivorous, plankton feeders, or even microcrustacean predators (Bruslé, 1981). The feeding plasticity of these species is reflected in the extensive terminology used by different authors to label the trophic behavior of mullets. Some examples include micro and meio-benthos feeders (Hickling, 1970), interface-feeders, surfaced boundaries such as air-water, mud–water, among mangrove roots and resuspended sediment (Odum, 1970), deposit feeders (Fagade and Olaniyan, 1973), benthic microphagous omnivore (Blaber and Whitfield, 1977) and limnobenthofagous (Laffaille *et al*., 2002). Mullets feed by sucking in food from the thick iliotrophic layer, inclined at $30^{o}$-$40^{o}$ to the substratum. Food then filtered and by pharyngeal filtering device to separate uneaten.

Several researches on the diet composition of mullets such as Romer and McLachlan (1986) reported *Liza richardsoni* of feeding transition from planktonic carnivore in juveniles to a diet consisting entirely of surf diatoms in larger fish.  Leh and Sasekumar (1991) found that mullet *Liza melinoptera* in size range 3.6-7.7 cm was mainly detritivore in the water column and on mangrove floor. *L. subviridis* in size range 3.9-10.5 cm was mainly herbivore in the water column when came in to feed inside mangrove forests during high tide. Shapiro (1998) studied gut contents of the *Liza ramada* in Lake Kinneret, Israel indicated that this fish was an omnivorous benthivore. Organic materials in the sand and mud, cladocera, calanoid copepoda (*Eudiaptomus* sp.) and diatoms were found in the diet.

Tammongkut (1984) studied the diet composition in three species of mullet. *Mugil buchanani*, *M. subviridis* and *M. vaigiensis*. Their main food items were diatoms, zooplankton, capillary root and pieces of mangrove leaves, detritus, organic and inorganic bottom particles. *M. vaigiensis* feed on most diversed food items of mainly diatom and asidian larvae. *M. subviridis* was next in rank in term of food spectra with diatoms as the main food items. However, *M. buchanani* was with limited food spectra different from *M. subviridis* and *M. vaigiensis*.

Niche partitioning in fish in the family Mugilidae in Tha-Chin mangrove forests, Samut Sakhon Province revealed that *L. subviridis*, being the largest and most dominant species in the area, feed mainly on diatom and organic detritus in equal proportion. *L. oligolepis*, was primarily herbivorous fish, feed on diatoms of more than 82% and 15% on organic detritus *L. parsia*, also primarily herbivorous fish, feeding on diatoms of more than 75%, 24% on cyanobacteria and the remaining was detritus. In contrast, *L. macrolepis*, also the large size mullet, was mainly detritivore with 99% detritus and only 1% on diatom (Paphavasit *et al*., 2000).

Laffaille *et al*. (2002) reported juveniles and adults (>100 mm) of *L. ramada* in the macrotidal salt marsh creeks in Mont Saint-Michel Bay. This fish come in the salt marsh during spring tide floods (43% of the tides) and return to coastal waters during ebb tide. The fish swallowed sediment including living organisms and organic detritus, amounts to 8% of its fresh body weight. Fish diet was dominated by diatoms and salt marsh plant detritus. Despite very short submersion periods, mullets filtered and ingested large quantities of sediment and organic matter of 31% of the stomach content.

Stomach content of the *L. ramada* inhabiting the Mira estuary showed that diatoms, *Melosira* and *Cyclotella* were the most common and abundant food items. Other diatoms, *Navicula*, *Nitzschia* and *Surirella* were preferential food items. It was found that the feeding activity of the thin-lipped grey mullets upturned the sediment as they ploughed through the sediment. The extent of these disturbed area increased exponentially with size of the fish in length. (Almeida, 2003). Dankwa and Blay (2005) studied the food items of grey mullets in the River Volta and River Pra Estuaries in Ghana. Diatoms, detritus materials and sand particles were the major items. Ingested sand particles of selected size range were specific to species.

**3. Niche Partitioning and Niche Overlap**

The number of fish species able to coexist on a resource gradient generally depends on the following factors (i) the total range of resource available in the community, (ii) the range utilised by each species and (iii) the tolerable amount of overlap in resource use among species. The wide range of habitats occupied by fish assemblages suggests a potential for different mechanisms of community control to be operative, so that different degrees of resource type may characterise fish assemblages within these habitats (Elliott and Hemingway, 2002). Niche partitioning in fish often reflect food partitioning and habitat partitioning go hand in hand. This is because most fish feed in the immediate are of the place where they live. Niche partitioning allow the partitioning of the food items and/or habitat, by two or more species, or age classes in a single species, in order to exploit the food supply to its fullest extent. Food partitioning may be conceived as an efficient way to exploit the total food resource in a habitat. The resource may be split up and used by a number of age classes in a single species. Niche partitioning may result in different feeding types, different components and diet utilized or different food sources in the same habitat. Differences in feeding structure morphology and time of feeding may also be the outcome of niche partitioning. Niche partitioning in fish sharing the same feeding grounds may be the alternative process in reducing competition for the same resources. Competition for food often leads to dietary switches or niche shifts. Food partitioning and diet switching both contributed to demonstrate that fish are extremely adaptable to the trophic surrounding in which they live (Gerking, 1994; Blaber, 1997). Whenever food or habitat partitioning is detected, niche overlap or diet overlap is customary. Degree of niche overlap is influenced by the distribution and abundance of resource and the range of resource utilization. Diet overlap often occurs, in the absence of competition, where prey organisms are superabundant. Discrete niches mostly detected in lower food abundance (Elliott and Hemingway, 2002). Niche overlaps, observed between species of the same family or order, indicated that morphology may be affecting the feeding behavior (Wootton, 1992).

Changes in diet and/or habitat during ontogeny are extremely common in fish. Fish partition food resources between species as well as size classes within a species. In both cases similar mechanisms affect segregation of resource use and these include differences in morphology, foraging behavior, period of activity and habitat use. Eggold and Motta (1992) studied ontogenetic dietary shifts in diet of *Mugil cephalus* found the fish of 20-30 mm SL ingest small amounts of sand and large amounts of organic matter and diatoms. Copepods, amphipods, ostracods, polychaetes and bivalves contribute minimally to the diet. The second ontogenetic trophic unit reported here occurs at 30-40 mm SL. These mullet ingest more sand, less organic matter, no zooplankton and more species of diatoms than the previous size classes. The third ontogenetic trophic unit occurs at 40->100 mm SL is characterized by greater ingestion of sand and diatom species and less ingestion of organic matter. The preference of different particle size was correlated to the feeding location as in the work of Odum (1968). He measured and compared the particle size in the digestive tract of mullet with that of the habitat sediment. *M. cephalus* selected smaller particles over larger particles in the sediment. Therefore, this preference could be correlated with (i) the availability of suitable food types found in the sediments or (ii) selectivity for the food items due to morphological parameters such as the size of the mouth, length of the gill rakers, inter-raker distances and the length of the intestines. Examples on ontogenetic niche shift in mullet as revealed from Romer and Mclachlan (1986) and Leh and Sasekumar (1991). From the wide diversity of prey types consumed by each species, and the occurrence of individual prey taxa in the diet of several species, it would appear that resource partitioning occurs via the degree of utilization of the prey rather than through its absence from the diet. This was evidenced in the study of niche partitioning in the four fish in the family Mugilidae in Tha-Chin mangrove forests, Samut Sakhon Province, *Liza subviridis*, being the largest and most dominant species in the area, feed mainly on diatom and organic detritus in equal proportion. *L. oligolepis*, was primarily herbivorous fish, feed on diatoms of more than 82% and 15% on organic detritus *L. parsia*, also primarily herbivorous fish, feeding on diatoms of more than 75%, 24% on cyanobacteria and the remaining was detritus. In contrast, *L. macrolepis*, also the large size mullet, was mainly detritivore with 99% detritus and only 1% on diatom (Paphavasit *et al*., 2000).

In Addition, *L. dumerilii* from the Volta Estuary showed the preference for zooplankton and diatoms while *M. cephalus* and *M. curema* ingested less zooplankton but more of green algae and polychaetes. In the Pra Estuary, *L. grandisquamis* ingested more of diatoms while polychaetes and zooplankton were prominent in the diet of *L. dumerilii*. Thus, species that ingested similar modal sizes of sand particles showed preferences for different food items. The preference of each mullet species in the estuaries for a particular particle size was a way of partitioning the resource to avoid interspecific competition, thus ensuring their coexistence. Niche overlap in spotted scat and tade mullet was evidenced by Boonruang *et al*. (1994). Diatom, algae and detritus were the main food items for these fish. Spotted scat in Pak Phanang mangrove plantations shared the same food sources with tade mullet, omnivore/detritivore, by being carnivore/detritivore (Paphavasit *et al*., 2000; Paphavasit *et al*., 2004).

## C. Materials and Methods

### 1. Stomach Content Analysis in Spotted Scat and Tade Mullet

Adult spotted scat larger than 8 cm and tade mullet larger than 10 cm from the mangrove plantations sites (PP1-PP3) and estuary sites (PP8-PP9) were collected by using the 1 cm mesh size gill net for half hour. A total of up to 40 individuals of each species were randomly taken from the catch. Fish were measured in total length (TL) and weighted in wet weight. These fish were preserved in 10% formalin. Feeding structure morphology in fish were examined namely mouth position, teeth, gill rakers, shape of stomach, number of pyloric caeca and intestinal length. After dissection, the stomach contents were determined by microscope examination. Only full stomachs or nearly full of identifiable food items were examined. Food items were identified to taxon with results presented as food items in diet composition. Enumeration of food items followed the method of Williams (1981). The following percentages were calculated for each food items.

$$P = (F/A) \times 100$$

where P represents percentage points of each food item; F represents total points of each food item and A represents total points of all food item

The results from percentage points of each food items were tested using a one-way analysis of variance (ANOVA) revealed a significant interaction between stations in high salinity period, independent simple *t*-test was used to compare the food items between low and high salinity. Prior to the analyses, data were transformed to $[\log_{10}(x+1)]$ the normality of distribution. A posteriori Tukey's HSD test at significance level of $p < 0.05$ was used in all tests.

The main food items were identified using the index of relative importance (IRI) of Pinkas *et al*. (1971), as modified by Hyslop (1980). IRI in stomach content of total spotted scat and tade mullet was describe feeding selection in each station and salinity.

$$IRI = (Cn + Cv) \times F$$

where IRI represents index of relative importance of the main food items, taxa or ecological groups; C*n* represents percentage numerical abundance as the total number of food items in all stomachs in a sample; C*v* represents percentage volumetric composition as the total volume of that taxa of prey and *F* represents percentage frequency of occurrence based on the number of stomachs in which a food items was found. The stomach content analysis for spotted scat as in Chapter III will only be concluded here.

**2. Niche Partitioning in Spotted Scat and Tade Mullet**

Comparative feeding types between spotted scat and tade mullet according to feeding structure morphology.

The frequency of each food category in stomachs of spotted scat and tade mullet were compared between station and salinity by using the degree of niche overlap and percentage overlap in the diets of the two co-occurring fish follows Krebs (1989):

$$\text{Niche overlap } O_{jk} = \sum^{n} p_{ij} p_{ik} / (\sum p_{ij}^{2} \sum p_{ik}^{2})^{1/2}$$

where $O_{jk}$ represents niche overlap between species *j* and species *k*; $p_{ij}$ represents proportion resource *i* is of the total resources used by species *j*; $p_{ik}$ represents proportion resource *i* is of the total resources used by species *k*; *n* re present total number of resources states

$$\text{Percentage overlap } P_{jk} = [\sum^{n} (\text{minimum } P_{ij}, P_{ik})]100$$

where $P_{jk}$ represents percentage overlap between species *j* and species *k*; $p_{ij}$, $p_{ik}$ represents proportion resource *i* is of the total resources used by species *j* and species *k*; *n* represents total number of resources states

## D. Results and Discussions

### 1. Feeding Types and Dietary Components in Spotted Scat

*Scatophagus argus* and *Liza planiceps* were abundant both in mangrove forests and estuarine waterways. The average total length was more than 8 cm and 10 cm in spotted scat and tade mullet respectively. Spotted scat showed broad diets, being omnivore, including microphytoplankton, protozoans, benthos and detritus. Food components in spotted scat did not show significant differences ($p$>0.05) due to salinity changes and in fish of different locality, mangrove forests and inside the Bay.

Zooplanktons were occasionally observed in their diets. Diatoms were the most common dietary components, occurring in stomach of 62% of spotted scat collected from mangrove fringes. *Pleurosigma/Gyrosigma* spp., pennate diatoms, were dominant, while *Oscillatoria* spp. were also found. Diatoms were also the most common dietary components, occurring in stomach of 54% of fish collected in the estuary. *Nitzschia* spp. were most dominant. As diatoms, being the most common dietary components, however spotted scat switched to protozoan, *Zoothamnium* spp. in low salinity period in the estuary in the range of 2.0-11.5 psu. During this period, the relative importance of protozoans, *Zoothamnium* spp. increased. These protozoans can be found in 97% of scat stomach examined. *Zoothamnium* spp. can be widely distributed in the estuarine area and in the shrimp ponds of salinity ranged 2-5 psu (Rucksapram, 1996).

Feeding selection of spotted scat in mangrove forest and estuarine waterways presented by IRI calculation. The IRI value showed spotted scat with broad diets showed preference on protozoan *Zoothaminum* spp. and *Oscillatoria* spp. Food items in stomachs of spotted scat correlated to food sources in Pak Phanang Estuary. Diatoms the genera *Nitzschia* spp., *Pleurosigma/Gyrosigma* spp. and cyanobacteria, *Oscillatoria* spp. were the most dominant. Zooplankton, benthos and detritus were also detected in the stomach content. Copepoda contributed more than 60% of the total zooplankton density. The second most abundant zooplankton was brachyuran larvae, larvae of shrimps and barnacle larvae.

**2. Feeding Types and Dietary Components in Tade Mullet**

Tade mullet were primarily herbivorous fish with diatoms as the major prey items. Their diets were detritus with large quantities of inorganic particles, zooplankton, benthos and protozoans (Figure 5.2 and Table 5.1). Diatoms, *Nitzschia* spp. and *Pleurosigma*/*Gyrosigma* spp., were the most common and abundant prey items in tade mullet collected from the mangrove forests. The diets in tade mullet collected from the estuary during high salinity range of 28.9-32.8 psu were similared to those from mangrove forests. Cyanophyceae in the diets of tade mullet collected from the mangrove forests in high and low salinity and from the estuary waterways in high salinity were significantly differenced ($p$<0.05). During the low salinity range of 2.3-5.6 psu, *Oscillatoria* spp. of 40% were found in the stomach content. Furthermore, Dinophyceae, protozoan, zooplankton and insect in stomachs of tade mullet from the mangrove forests and the estuarine waterways were significantly differenced ($p$<0.05).

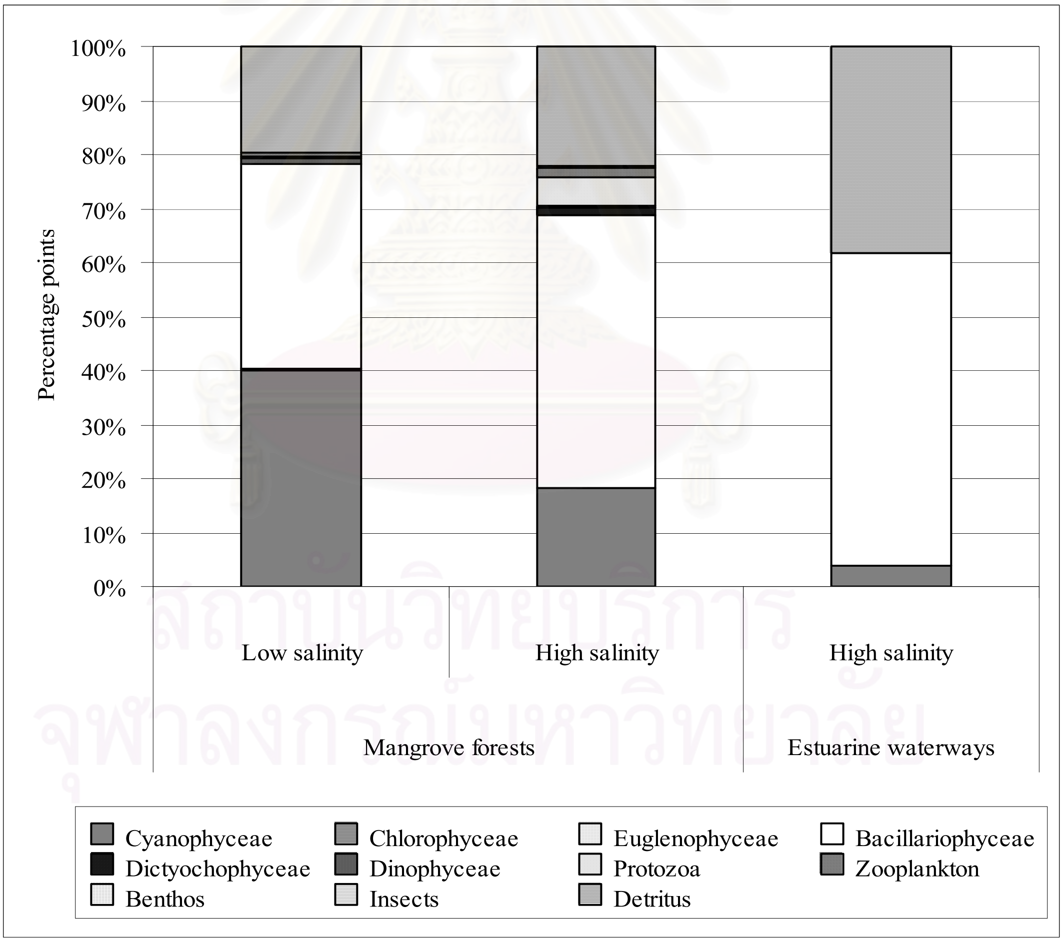



Figure 5.2 Dietary components in tade mullet, *Liza planiceps* at different salinity in mangrove forests and estuarine waterways in Pak Phanang Estuary, Nakhon Si Thammarat Province

Table 5.1 Density of prey items of tade mullet, *Liza planiceps* in mangrove forests and estuarine waterways (percentage of each prey items by all prey items are listed as Dominant (D) = 80-100% Abundant (A) = 60-79% Frequent (F) = 40-59% Occasional (O) = 20-39% Rare (R) = >0-19% NF = Not Found)

| **Prey items** | **Low salinity** | **High salinity** | **High salinity** |
|---|---|---|---|
| | Mangrove forests | Mangrove forests | Estuarine waterways |
| **Cyanophyceae** | | | |
| *Anabaena* | O | R | R |
| *Merismopedia* | R | R | R |
| *Oscillatoria* | R | R | R |
| *Spirulina* | R | R | NF |
| **Chlorophyceae** | R | R | R |
| **Euglenophyceae** | | | |
| *Phacus* | R | R | NF |
| *Strombomonas* | R | NF | NF |
| **Bacillariophyceae** | | | |
| Centric diatoms | R | R | R |
| Pennate diatoms | O | F | F |
| **Dictyochophyceae** | | | |
| *Dictyocha* | NF | R | NF |
| **Dinophyceae** | R | R | R |
| **Protozoan** | | | |
| Tintinnid | R | R | R |
| Foraminifera | R | R | R |
| **Zooplankton** | | | |
| Rotifer | R | R | R |
| Ostracod | R | R | NF |
| Cirripedia larvae | R | R | R |
| Copepod norplii | R | R | R |
| Copepod | R | R | R |
| Mysidacea | NF | R | NF |
| Zoea of brachyura | NF | R | NF |

Table 5.1 (Continued)

| Prey items | Low salinity | High salinity | High salinity |
|---|---|---|---|
| | Mangrove forests | Mangrove forests | Estuarine waterways |
| **Benthos** | | | |
| Nematode | R | R | R |
| Polychaete larvae | NF | R | NF |
| Gastropod larvae | NF | R | R |
| Bivalve larvae | R | R | R |
| Amphipod | NF | R | NF |
| **Insects** | NF | R | NF |
| **Detritus** | | | |
| Plant tissue | R | R | R |
| Crustacean fragments | R | R | R |
| Fish scales | R | R | O |
| Sand grains | R | R | O |

Tade mullet showed feeding preference in microphytoplankton as primary consumed. Zooplankton, benthos and detritus were found in small proportion. From this study microphytoplankton, as diatom being the dominant group, corresponded with the findings in *M. subviridis* and *M. vaigiensis* with diatom as the dominant food items (Tammongkut, 1984). While, Romer and McLachlan (1986) found *L. richardsoni* feed on surf diatoms taken from the air-water interface as the principal source of food. Stomach contents revealed a feeding transition from planktonic carnivore in juveniles to a diet consisting entirely of surf diatoms in adult fish.

Paphavasit *et al*. (2000) showed feeding preference of Mugilidae in Tha-Chin mangrove forests, Samut Sakhon Province. *L. subviridis*, being the largest and most dominant species in the area, feed mainly on diatom and organic detritus in equal proportion. *L. oligolepis*, was primarily herbivorous fish, feed on diatoms of more than 82% and 15% on organic detritus *L. parsia*, also primarily herbivorous fish, feeding on diatoms of more than 75%, 24% on cyanobacteria and the remaining was detritus. Moreover, stomach content of the *L. ramada* inhabiting the Mira estuary found the genera *Melosira* and *Cyclotella* were the most common and abundant food items, although the genera *Navicula*, *Nitzschia* and *Surirella* were also classified as preferential food items (Almeida, 2003). Furthermore, the substratum in such systems is frequently covered with a carpet of benthic diatoms and other algae. They could adaptation to feeding on surface sediments with the associated organic components. They feed by taking up the surface layer of the substratum or by grazing on submerged clay and plant surfaces (Odum, 1970). Most mullets ingest large quantities of inorganic particles together with food items. It was found that the volume of ploughed sediment that resulted from the feeding activity of the mullets, and the correspondent disturbed area increased exponentially with the length of the fish. Juvenile and adult mullet such as *L. dumerilii*, *L. macrolepis*, *L. richardsonii*, *M. cephalus*, *M. capensis* and *Valamugil cunnesius* consumed mainly organic matter meanwhile diatoms, filamentous algae, flagellates and foraminifera were also found (Whitfield, 1998).

Feeding selection of tade mullet in mangrove forest and estuarine waterways presented by IRI calculation. The IRI value showed microphytoplankton, diatoms both pennate and centric diatoms and cyanobacteria, *Oscillatoria* spp. and *Anabaena* spp. were the most dominant. Detritus was the second most abundant in stomach. Zooplankton, benthos and detritus were also detected in the stomach content in Table 5.2 and Figure 5.3-5.4.

Table 5.2 List of prey items in tade mullet stomachs at different salinity from mangrove forests and estuarine waterways and index of relative importance (IRI) value (C*n* = percentage numerical abundance, C*v* = percentage volumetric composition, *F* = percentage frequency of occurrence)

| **Prey items** | **Low salinity : Mangrove forests** | | | | **High salinity : Mangrove forests** | | | | **High salinity : Estuarine waterways** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI |
| *Anabaena* | 20.597 | 8.541 | 60.000 | 1748.289 | 4.100 | 3.880 | 37.778 | 301.493 | 0.963 | 0.128 | 50.000 | 54.540 |
| *Merismopedia* | 2.214 | 0.082 | 33.333 | 76.541 | 10.352 | 0.330 | 25.000 | 267.035 | 1.498 | 0.037 | 26.667 | 40.933 |
| *Oscillatoria* | 16.740 | 9.441 | 90.000 | 2356.317 | 3.110 | 2.785 | 73.333 | 432.286 | 1.343 | 1.602 | 90.000 | 265.041 |
| *Spirulina* | 0.456 | 0.083 | 25.000 | 13.475 | 0.610 | 0.002 | 1.111 | 0.680 | - | - | - | - |
| *Actinastrum* | 0.100 | 0.117 | 15.000 | 3.262 | - | - | - | - | - | - | - | - |
| *Closterium* | 0.012 | 0.101 | 3.333 | 0.376 | - | - | - | - | - | - | - | - |
| *Cosmarium* | 0.010 | 0.056 | 6.667 | 0.445 | - | - | - | - | 0.029 | 0.025 | 3.333 | 0.179 |
| *Mougeotia* | 0.051 | 0.045 | 13.333 | 1.278 | - | - | - | - | - | - | - | - |
| *Scenedesmus* | 0.010 | 0.034 | 36.667 | 1.638 | 0.006 | 0.016 | 1.111 | 0.025 | 0.004 | 0.001 | 6.667 | 0.036 |
| *Phacus* | 0.139 | 0.346 | 40.000 | 19.399 | 0.003 | 0.007 | 2.222 | 0.023 | - | - | - | - |
| *Strombomonas* | 0.050 | 0.085 | 3.333 | 0.449 | - | - | - | - | - | - | - | - |
| Centric diatoms | 8.672 | 14.178 | 96.667 | 2208.827 | 4.901 | 4.509 | 88.889 | 836.468 | 0.744 | 0.479 | 90.000 | 110.119 |
| Pennate diatoms | 29.062 | 41.100 | 100.000 | 7016.180 | 45.862 | 41.991 | 98.889 | 8687.678 | 57.038 | 93.399 | 100.000 | 15043.764 |
| *Dictyocha* | - | - | - | - | 0.004 | 0.021 | 6.667 | 0.172 | - | - | - | - |
| Dinophyceae | 1.131 | 1.730 | 40.000 | 114.468 | 1.574 | 1.222 | 60.000 | 167.794 | 0.102 | 0.102 | 50.000 | 10.179 |

Table 5.2 (Continued)

| Prey items | Low salinity : Mangrove forests | | | | High salinity : Mangrove forests | | | | High salinity : Estuarine waterways | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI | C*n* | C*v* | *F* | IRI |
| Tintinnid | 0.378 | 1.534 | 90.000 | 172.113 | 5.000 | 1.811 | 87.778 | 597.897 | 0.054 | 0.109 | 70.000 | 11.443 |
| Foraminifera | 0.151 | 0.954 | 60.000 | 66.345 | 0.300 | 1.067 | 70.000 | 95.695 | 0.056 | 0.219 | 50.000 | 13.761 |
| Rotifer | 0.089 | 0.645 | 53.333 | 39.131 | 0.114 | 0.583 | 42.222 | 29.436 | 0.009 | 0.035 | 20.000 | 0.882 |
| Ostracod | 0.006 | 0.053 | 3.333 | 0.195 | 0.008 | 0.013 | 3.333 | 0.069 | - | - | - | - |
| Cirripedia larvae | 0.012 | 0.238 | 16.667 | 4.172 | 0.111 | 1.009 | 26.250 | 29.382 | 0.029 | 0.656 | 33.333 | 22.834 |
| Copepod norplii | 0.150 | 6.303 | 60.000 | 387.163 | 0.406 | 5.814 | 72.222 | 449.208 | 0.013 | 0.190 | 40.000 | 8.103 |
| Copepod | 0.231 | 6.432 | 43.333 | 288.701 | 1.100 | 10.010 | 68.889 | 765.379 | 0.003 | 0.173 | 30.000 | 5.267 |
| Mysidacea | - | - | - | - | 0.022 | 0.461 | 2.222 | 1.074 | - | - | - | - |
| Zoea of brachyuran | - | - | - | - | 0.500 | 8.508 | 5.556 | 50.048 | - | - | - | - |
| Nematode | 0.235 | 2.170 | 63.333 | 152.360 | 0.326 | 1.150 | 68.889 | 101.693 | 0.029 | 0.464 | 53.333 | 26.335 |
| Polychaete larvae | - | - | - | - | 3.271 | 4.444 | 14.760 | 113.873 | - | - | - | - |
| Gastropod larvae | - | - | - | - | 0.035 | 0.412 | 17.500 | 7.831 | 0.006 | 0.082 | 16.667 | 1.481 |
| Bivalve larvae | 0.052 | 1.227 | 26.667 | 34.101 | 0.016 | 0.151 | 16.667 | 2.778 | 0.001 | 0.023 | 6.667 | 0.161 |
| Amphipod | - | - | - | - | 0.025 | 7.022 | 1.111 | 7.830 | 0.002 | 1.590 | 3.333 | 5.308 |
| Insects | - | - | - | - | 0.0005 | 0.003 | 3.333 | 0.013 | - | - | - | - |
| Plant tissue | 9.810 | 1.226 | 26.667 | 294.300 | 9.871 | 1.405 | 18.750 | 211.424 | 2.037 | 0.089 | 20.000 | 42.512 |
| Crustacean fragments | 9.140 | 1.497 | 43.333 | 460.948 | 9.680 | 0.505 | 43.750 | 445.614 | 6.035 | 0.190 | 53.333 | 332.002 |
| Fish scale | 0.501 | 1.781 | 6.667 | 15.212 | 1.911 | 2.040 | 6.667 | 26.339 | 30.000 | 0.409 | 3.333 | 101.365 |

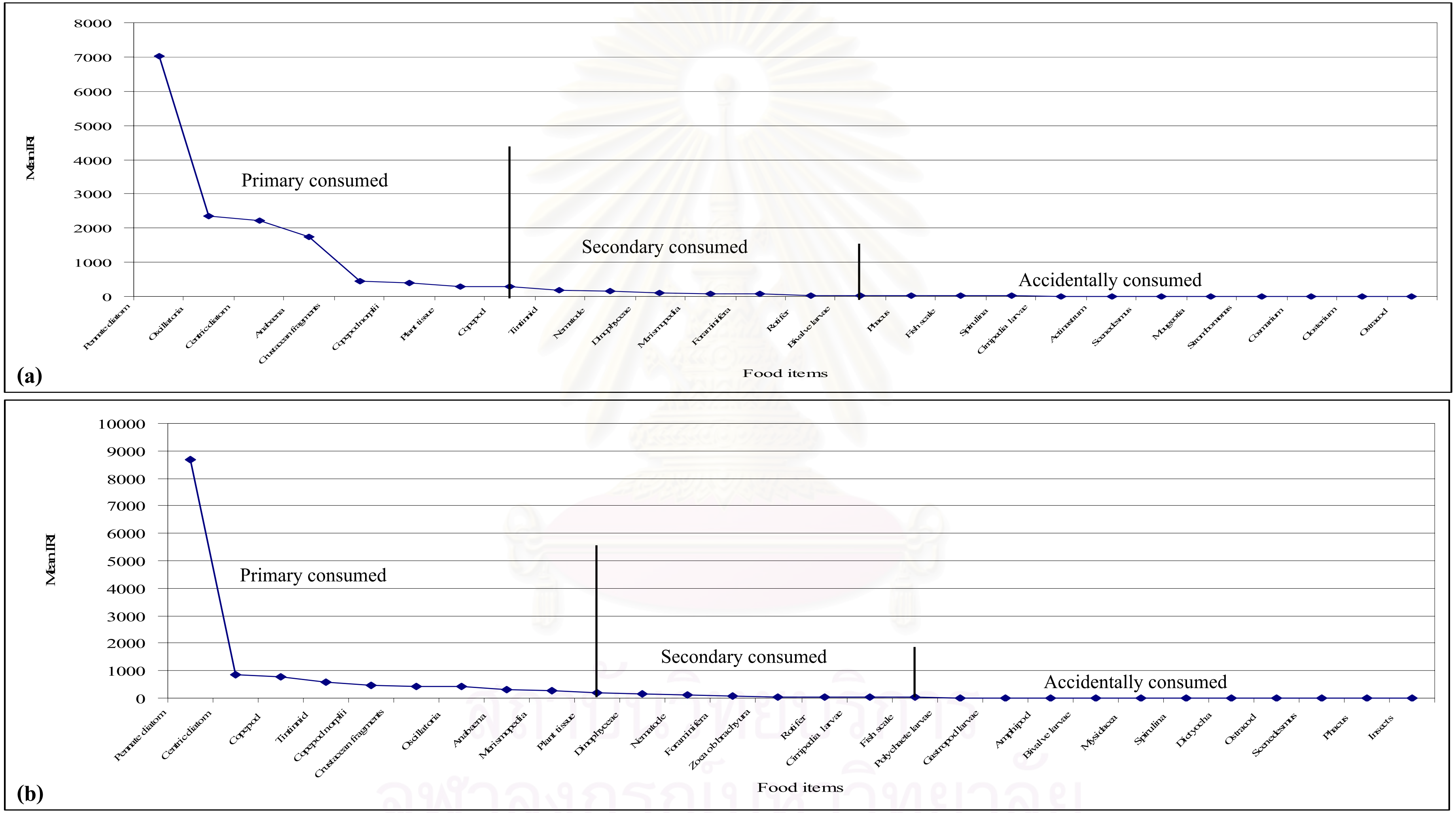



Figure 5.3 Diet preferences of tade mullet in Pak Phanang mangrove forests during low salinity period (a) and high salinity period (b)

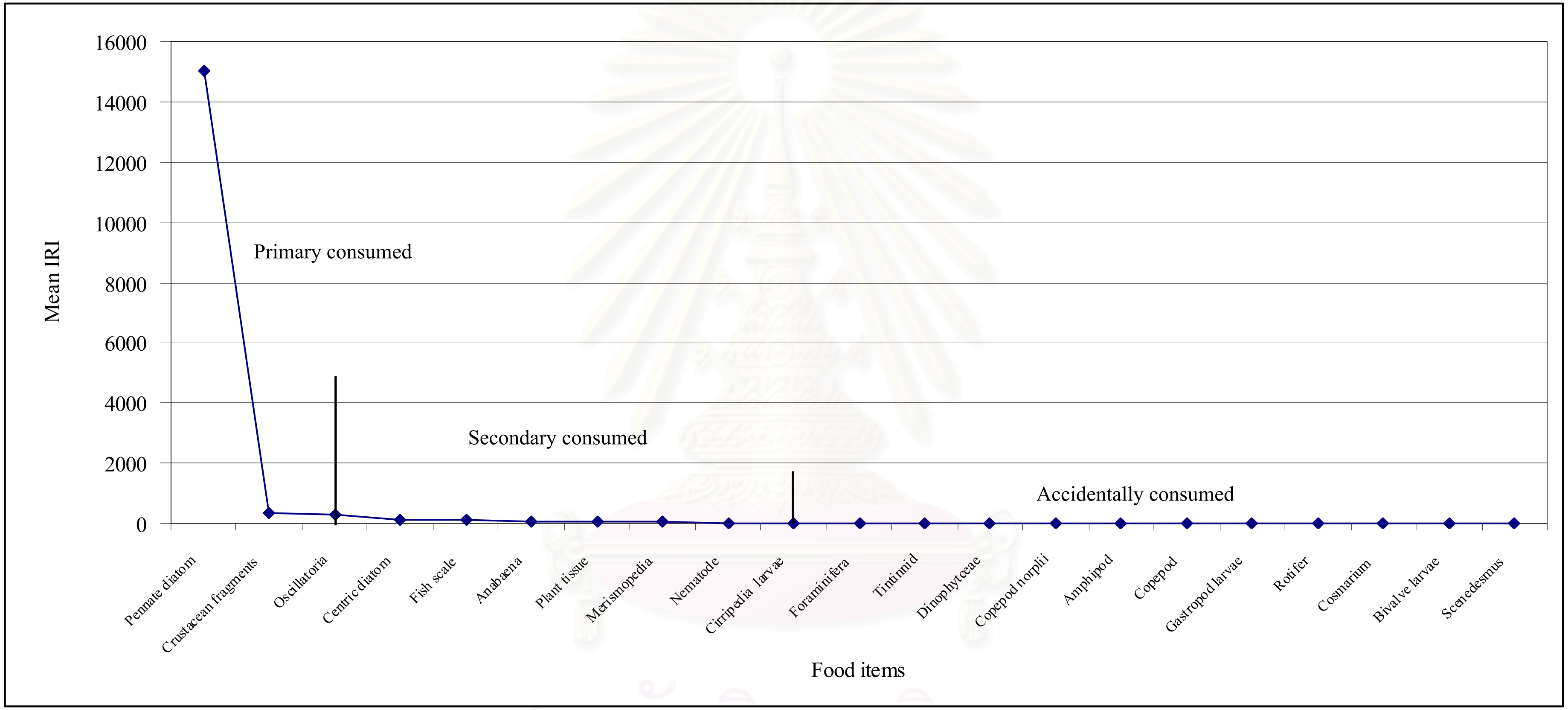



Figure 5.4 Diet preferences of tade mullet in estuarine waterways during high salinity period

### 3. Degree of Niche Overlap

Niche overlap in the co-occurring fish, *Scatophagus argus* and *Liza planiceps* were evidenced as shown in Table 5.3-5.4. Niche overlap in food items occurred mainly microphytoplankton and detritus. Microphytoplankton, Bacillariophyceae in especially pennate diatoms in *Nitzschia* and *Pleurosigma/Gyrosigma* genera and Cayanophyceae, *Oscillatoria* and *Anabaena* genera were mainly niche overlap. Detritus such as sand particle, plant tissue and crustacean fragment were found dominant in both species. The result showed niche overlap and percentage overlap between spotted scat and tade mullet in mangrove forests higher than estuarine waterways and also found diversed food items such as Euglenophyceae, Dictyochophyceae and insects.

Table 5.3 Niche overlap and percentage overlap in prey items of spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* in mangrove forests at different salinity

| **Prey items** | **Low salinity** | | **High salinity** | |
|---|---|---|---|---|
| | Spotted scat | Tade mullet | Spotted scat | Tade mullet |
| | Percentage points | Percentage points | Percentage points | Percentage points |
| Cyanophyceae | 35.453 | 40.008 | 27.735 | 18.172 |
| Chlorophyceae | 0.008 | 0.183 | - | 0.006 |
| Euglenophyceae | - | 0.189 | - | 0.003 |
| Bacillariophyceae | 61.678 | 37.734 | 61.704 | 50.763 |
| Dictyochophyceae | - | 0.004 | - | - |
| Dinophyceae | - | 1.131 | - | 1.574 |
| Protozoan | 1.301 | 0.530 | 1.370 | 5.300 |
| Zooplankton | 0.364 | 0.416 | 0.049 | 1.760 |
| Benthos | 0.095 | 0.290 | 0.471 | 0.452 |
| Insects | - | - | 0.001 | 0.0005 |
| Detritus | 1.101 | 19.514 | 8.670 | 21.970 |
| | Niche overlap = 0.907 | | Niche overlap = 0.961 | |
| | Percentage overlap = 75.285 % | | Percentage overlap = 79.476 % | |

Table 5.4 Niche overlap and percentage overlap in prey items of spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* in high salinity of estuarine waterways

| **Prey items** | **High salinity** | |
|---|---|---|
| | Spotted scat | Tade mullet |
| | Percentage points | Percentage points |
| Cyanophyceae | 21.714 | 3.805 |
| Chlorophyceae | - | 0.004 |
| Euglenophyceae | - | - |
| Bacillariophyceae | 53.833 | 57.803 |
| Dictyochophyceae | - | - |
| Dinophyceae | - | 0.102 |
| Protozoan | 16.565 | 0.110 |
| Zooplankton | 0.349 | 0.054 |
| Benthos | 3.822 | 0.039 |
| Detritus | 3.716 | 38.083 |
| | Niche overlap = 0.795 | |
| | Percentage overlap = 61.552 % | |

Niche overlap in fish will occur in the absence of competition, where prey organisms are abundant, discrete niches can arise from lower food abundance. Therefore, where food organisms are restricted discrete feeding groups will be established, with either geographic or dietary boundaries. Superabundance refers to an availability of prey greater than that required to maintain the fish assemblage (Elliott and Hemingway, 2002). Niche overlap quantifying the sharing of food resource items between spotted scat and tade mullet varies from 0.795-0.961, described high dietary overlap namely microphytoplankton and detritus. Food items in stomachs of spotted scat and tade mullet correlated to food sources in Pak Phanang Estuary. Microphytoplankton and organic detritus as total forest biomass were high density. Organic detritus in form of underground, pneumatophore and seedling biomass in the mangrove plantations of Pak Phanang Estuary was on the average of 443.06 $g/m^2$. While the average density of microphytoplankton ranged from $1.28x10^3$ to $3.45x10^4$ cells/l in high salinity and from $6.51x10^3$ to $1.59x10^5$ cells/l in low salinity period. Moreover, resource partitioning to be any substantial difference in resource use between coexisting species, may be due to competition and other factors. Since resource partitioning is important in the organization of assemblages, species ultimately segregate along resource dimensions and/or decrease niche breadth in order to maintain a minimum level of niche separation as the number of species in the assemblage increases. The degree of niche overlap is also influenced by the shape of the resource utilization function and the distribution and abundance of resources (Elliott and Hemingway, 2002). The presence of spotted scat and tade mullet in a particular habitat has been widely discussed as a possible strategy for avoiding trophic competition (Pianka, 1980; Angel and Ojeda, 2001), and optimizing available resources (Jacksic, 1981).

**4. Comparative Study of Feeding Structure Morphology**

Comparative study on feeding structure morphology in spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* is shown in Table 5.5.

***Scatophagus argus***

The mouth is subterminal indicating the benthic feeding habit. The small size mouth is nonprotrusible. Teeth mainly villiform teeth appear on both the upper and lower lip in numerous rows. Ciliiform teeth also appear on tongue. When mouth closed, the maxilla covered by preorbital bone. Short gill rakers are found. The esophagus is short and straight. The stomach is U-shape with 10-19 pyloric caeca. The intestine length/body length ratio varies from 1.8-3.3.

***Liza planiceps***

The v-shape mouth is terminal position. The mouth is moderate size and premaxillae protractile. The maxillae are excluded from the gape of the mouth. The premaxillae, the ciliiform teeth, bear fine serrations. The lower jaw, the ciliiform teeth, the dentaries are held together at the symphysis by a very short ligament which allows only slight movement. The pharyngeal cavity is perforated by the gill slits connecting to the branchial chamber. There are four pairs of gills, each with two rows of gill rakers which serve to protect the gill opening. The rakers of the anterior row on each gill arch are longest in the middle of the arch, shortening towards each end. The stomach consists of two regions: an anterior gizzard-like pyloric region or the pylorus, and a posterior conical cardiac region and the five pyloric caeca. The gizzard is thick muscular layer that surrounds this portion of the stomach. The circular muscles in the distal region close to the pylorus are particularly well developed. The gizzard can grind the food with stones that swallowed and pass it back to the true stomach. The long intestine starts from the anterior end of the pylorus, takes a loop and passes back above the right half of the stomach, forming a relatively thick duodenum.

Table 5.5 Comparative study on feeding structure morphology in spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps*

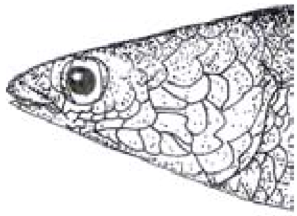
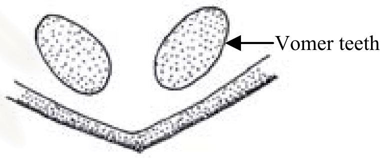
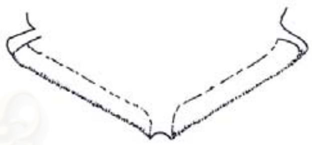
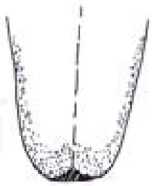
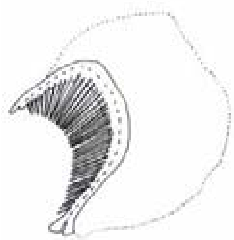
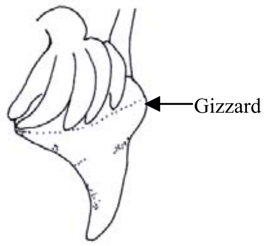
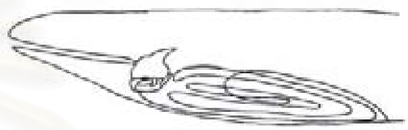
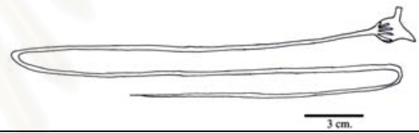
| **Characteristics** | ***Scatophagus argus*** | ***Liza planiceps*** |
|---|---|---|
| 1. Position of mouth | Subterminal mouth  Width of the mouth gape 0.61±0.01 cm. | Terminal mouth  Width of the mouth gape 0.90±0.01 cm. |
| 2. Mouthparts and feeding structure | | |
| - Upper lip | Villiform teeth (inner band 5-6)  | Ciliiform teeth (inner band 2-4)  |
| - Lower lip | Villiform teeth (inner band 6-7)  | 1 row of sparse ciliiform teeth  |
| - Tongue | Ciliiform teeth  | Ciliiform teeth  |
| - Gill rakers | Short gill rakers (gill rakers on lower limb of first gill arch 13-20)  | Long gill rakers (gill rakers on lower limb of first gill arch 68-97)  |

Table 5.5 (Continued)

| **Characteristics** | ***Scatophagus argus*** | ***Liza planiceps*** |
|---|---|---|
| 3. Digestive system<br>- Stomach | U-shape, Number of pyloric caeca 10-20<br> | With gizzard, Number of Pyloric caeca 5<br> |
| - Intestine | <br>The intestine length/body length ratio varies from about 1.8-3.3<br> | <br>The intestine length/body length ratio varies from about 2.0-4.2<br> |

This study revealed that the two co-occurring fish, spotted scat, *Scatophagus argus* and tade mullet *Liza planiceps* utilized the mangrove forests and estuarine waterways in Pak Phanang Estuary, Nakhon Si Thammarat province, southern Thailand as feeding grounds. Niche overlap in term of food items, mainly microphytoplankton and detritus were evidenced. Diatoms, cyanobacteria and detritus are the major natural diets of *Scatophagus argus* and *Liza planiceps* (Blaber, 1976, 1977; Almeida *et al*., 1993; Monkolprasit, 1994; Jeyaseelan, 1998; Whitfield, 1998). From our study, the spotted scat showed broad diets, being omnivore, including microphytoplankton, protozoans, benthos, detritus and zooplanktons. These fish showed high adaptability in the food resources presented in the habitat. As diatoms, being the most common dietary components, however spotted scat switched to protozoans, *Zoothamnium* spp. in low salinity habitats.

As revealed from Piumsomboon *et al*. (2004) on the microphytoplankton communities in the Pak Phanang Estuary that diatom contributed more than 75% of total microphytoplankton abundance. Dominant genera found in the area were *Skeletonema*, *Cylindrotheca*, *Nitzschia* and *Surirella*. Cyanophyceae, *Anabaena*, was another dominant microphytoplankton in the area. From previous studies showed that spotted scat, *Scatophagus argus*, have the opportunistic feeding strategy with very broad diets. Arrunyagasemsuke (1975) reported the main food items found in spotted scat collected from coastal area of Chon Buri Province were hydroids, amphipods, lucifers and copepods. Spotted scat diets in the mangrove forests in Phangnga and Surat Thani Provinces in southern Thailand were mainly of omnivorous fish, comprised of diatoms, rotifers, foraminifera, polychaetes, nematodes, detritus, arthropod crustacean, molluscs and fish (Monkolprasit, 1994). However the spotted scat collected from the Tha-Chin mangrove estuary, Samut Sakhon in the Inner Gulf of Thailand were detritivore with more than 81% of the total stomach content. Crustacean fragments namely amphipods, mysids, copepods, diatoms, polychaetes and fish scales were also observed.

Fish in the family Mugilidae, although relatively generalized in terms of diet composition, exhibited marked feeding specializations that help reduced intra-and interspecific composition according to Romer and McLachlan (1986), Shapiro (1998), Blaber (2000) and Paphavasit *et al.* (2000). Blaber concluded that Mugilidae were iliophagous due to their feeding on the organisms in and on the substratum by ingestion of the substratum. Their diet consisted largely of benthic algae, bacteria, meiofauna and smaller epifauna. As revealed his previous works in the ten species of mullet in southeast Africa, foraminifera, the diversed food spectra were flagellate protozoan, pennate diatoms, unicellular and filamentous green algae, blue-green algae, ostracods, small Assimineid gastropods and harpacticoid copepods. In addition, gut contents of the thin-lipped grey mullet, *Liza ramada*, in Lake Kinneret indicates that this fish is an omnivorous benthivore. The most important food for *L. ramada* is the organic material present in the sand and mud. *L. ramada* also fed upon Cladocera, Copepoda and diatoms. Calanoid copepods, *Eudiaptomus* sp., were also found among the food organisms (Shapiro, 1998).

Tammongkut (1984) studied the diet composition in three species of mullet *M. buchanani*, *M. subviridis* and *M. vaigiensis* in coastal water of Kapoe District, Ranong Province. Their main food items were diatoms, zooplankton, capillary root and pieces of mangrove leaves, detritus, organic and inorganic bottom particles. *M. vaigiensis* feed on most diversed food items of mainly diatom and asidian larvae. *M. subviridis* was next in rank in term of food spectra with diatoms as the main food items. However, *M. buchanani* was with limited food spectra different from *M. subviridis* and *M. vaigiensis*. Paphavasit *et al.* (2000) showed niche partitioning in the four fish in the family Mugilidae in Tha-Chin mangrove forests, Samut Sakhon Province *Liza subviridis*, being the largest and most dominant species in the area, feed mainly on diatom and organic detritus in equal proportion. *L. oligolepis*, was primarily herbivorous fish, feed on diatoms of more than 82% and 15% on organic detritus *L. parsia*, also primarily herbivorous fish, feeding on diatoms of more than 75%, 24% on cyanobacteria and the remaining was detritus. In contrast, *L. macrolepis*, also the large size mullet, was mainly detritivore with 99% detritus and only 1% on diatom. In our study, tade mullet, *Liza planiceps*, was primarily herbivorous fish with diatoms as the major food items. The three food items, in respective importance, detritus with large quantities of inorganic particles, zooplankton and benthos, were occasionally detected. The observations and stomach content analysis of Romer and McLachlan (1986) demonstrated that the mullet have a feeding transition from planktonic carnivore in juveniles to a diet consisting entirely of surf diatoms in larger fish. This change in diet commonly occurred at a standard length of 50–135 mm. Fish larger than 135 mm fed entirely on surf diatoms which were ingested together with large quantities of beach sediment. Furthermore, energy, ash, protein, fat and carbohydrate content determinations indicate a high food quality of surf diatoms. It is concluded that surf diatom accumulations form a richly concentrated and reliable food source of high nutritional quality for these fish. Possible widespread grazing on surf diatoms by mullets is considered.

Niche partitioning in particular food partitioning, in these two co-occurring species was evidenced as tactics each species used to exploit food sources more efficient than other according to Nilsson in 1967 as cited by Gerking (1994). The composition of the diet of mullets from different localities is likely to differ, depending on the abundance and types of food organisms present (Blaber, 1977; Buslé, 1981). Tade mullet had taken the advantage of the microphytoplankton rich environment as in the Pak Phanang Estuary to feed primarily on diatoms and cyanobacteria. Their feeding structure morphology are typical of those in phytophagous fish. The mullet usually feed by taking up the surface layer of the substratum, carpeted by benthic diatoms and other microalgae and detritus. Along with these food materials, considerable quantities of coarse sand grains and undecayed parts of macroflora were also gulped in. These were sieved out before the food enters the esophagus. This was done by means of the pharyngeal cushions and the gill rakers. Thus, the coarse material is rejected, the very fine material is released with the water leaving the gill slits, and the particles of the desired size range are retained by the gill apparatus for being passed through the digestive tract. The ciliiform teeth on the cushions formed only a straining cushion of that side. The esophagus was narrow deep groove between the two pharyngeal cushions leads into the anterior wide muscular esophagus. The esophagus conveyed the strained food material from the pharynx to the stomach.

As the mullet has no specialized masticatory apparatus, the stomach of the mullet has the muscular gizzard, where the grinding of food take place. The gizzard was thick muscular layer that surrounds this portion of the stomach. The circular muscles in the distal region close to the pylorus are particularly well developed. Gizzard serves to break down the cell walls of bacteria, cyanobacteria, diatoms and filamentous red and green macroalgae that are ingested along with some quantities of sand and other sedimentary material. The ingested sand grains were also responsible for grinding action in the stomach together with muscular contractions of the stomach wall. Although without pharyngeal teeth, the tade mullet have the physical equipment to process plant food with numerous jaw teeth, muscular stomach, gizzard and ingested sand grained in the stomach. The intestine was quite long. The general pattern found in the gut lengths of fish is that the highest relative gut lengths occur in herbivore because the digestion of plant materials takes more time than digestion of animal tissues (Piet, 1998). Results of the study show that mullets with a higher relative gut length consume more plant material. Longer guts could be an adaptation to increasing the digestive area and ensure that such food items are properly digested. The higher consumption of zooplankton be related to their smaller relative gut length, although diatoms were also major food items.

Spotted scat, *Scatophagus argus*, on the other hand being highly adaptable, have taken the opportunity to fully exploited other food sources than limited only on microphytoplankton. These fish were mainly benthic omnivore with subterminal mouth and short gill rakers as the good indicators. Zooplankton, benthos and detritus were occasionally detected. Their digestive systems have allowed the broader diets other than plants with U-shape stomach and numerous pyloric caeca of 10-20. These caeca allowed optimized digestion of diversed food items. This feature resembled those found in carnivore usually with shorter digestive tracts with a great number of villi and pyloric caeca (Buddington *et al.*, 1997). The intestinal length to body size was 1.8-3.3.

## E. Conclusion

Spotted scat, *Scatophagus argus* and tade mullet, *Liza planiceps* were two co-occurring fish in Pak Phanang Estuary, Nakhon Si Thammarat Province. These fish utilized the mangrove forests and estuarine waterways as feeding grounds. The relative importance of different components of the diet was assessed from stomach contents by using the points method and index of relative importance (IRI). Spotted scat showed broad diets, being omnivore, including microphytoplankton, protozoans, benthos and detritus. Zooplanktons were occasionally observed in their diets. Diatoms were the most common dietary components, occurring in stomach of 62% of spotted scat collected from mangrove fringes. *Pleurosigma*/*Gyrosigma* spp. were dominant, while *Oscillatoria* spp., cyanobacteria, were also found. Diatoms were also the most common dietary components, occurring in stomach of 54% of fish collected in the estuary. *Nitzschia* spp. were most dominant. As the salinity in the estuary were lowered in the range of 2.0-11.5 psu, the relative importance of protozoans, *Zoothamnium* spp. increased. These protozoans can be found in 97% of spotted scat stomach examined. The different components of the diets for spotted scat collected from the mangrove forests and the estuary were similar. No significant difference ($p$>0.05) in the food components in spotted scat due to salinity changes was observed.

The study confirmed that tade mullet were primarily herbivorous fish with diatoms as the major food items. Their diets were detritus with large quantities of inorganic particles, zooplankton, benthos and protozoans. The three latter groups were occasionally detected. Pennate diatoms, *Nitzschia* spp. and *Pleurosigma*/*Gyrosigma* spp., were the most common and abundant food items in tade mullet collected from the mangrove forests. The diets in tade mullet collected from the estuary during high salinity range of 28.9-32.8 psu were similared. However in the low salinity range of 2.3-5.6 psu, *Oscillatoria* spp. were found 40% in stomach of fish examined.

Niche overlap in food items, mainly microphytoplankton and detritus, were evidenced in spotted scat and tade mullet diets. Niche partitioning between spotted scat and tade mullet were shown by differences in feeding morphology and behavior, digestive system and seasonal shifts in relative importance of different components in diets.

# CHAPTER VI

# SYNTHESIS AND RECOMMENDATION

## A. Research Synopsis

*Scatophagus argus*, spotted scat, is one of the economically important fish in the mangrove forests of Pak Phanang forests of Pak Phanang Estuary, Nakhon Si Thammarat Province. This fish is common along the coastline, mudflats, estuarine and sometimes carried up the river by tides. Feeding ecology of spotted scat *Scatophagus argus*, Linnaeus in mangrove forests Pak Phanang Estuary, Nakhon Si Thammarat Province revealed the importance of mangrove forests not only as habitat but as feeding and nursery ground for spotted scat larvae and juveniles. The study also demonstrated role of mangrove forests in supporting the availability of habitat and food sources for adults. High diversity and abundance of food sources ranged from organic detritus in term of forest biomass, microphytoplankton, zooplankton and benthos. Diatoms and cyanobacteria were the predominant microphytoplankton. Zooplankton diversity is dominated by copepod and contributed more than 60%. The second most abundance zooplankton was brachyuran zoea, shrimp larvae and cirripedia nauplii. Gastropods, nematodes and insect larvae were found as dominant benthos.

Pak Phanang mangrove forest also provided the important food sources, habitats and nursery grounds for fish of many commercial species. Habitat utilization in fish communities in Pak Phanang mangrove forest can be categorized as marine migrant fish of 13 families, namely Megalopidae, Bragidae, Ariidae, Plotosidae, Mugilidae, Phallostethidae, Hemiramphidae, Aplocheilidae, Scorpaenidae, Sillaginidae, Sciaenidae, Callionymidae and Tetraodontidae. Theses fish utilized mangrove area for feeding ground. True resident fish species in this area, a total of 9 families namely Engraulidae, Ambassidae, Leiognathidae, Gerreidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae and Cynoglossidae. While, the partial residents of 5 families namely Clupeidae, Atherinidae, Syngnathidae, Blenniidae and Sphyraenidae. These fish spend their time mostly in mangrove forest for nursery, foraging and seek refuge from predation.

Spotted scat from this area showed flexibility in the feeding ecology. Being omnivore and opportunist feeder, their diets ranged from microphytoplankton, protozoans, zooplankton, benthos and detritus. They switch from one type of prey to another as the relative abundance of the prey types changes. During the low salinity period, adult spotted scat feed predominantly on *Zoothamnium* spp. The diets during high salinity period were more diversed. Ontogenetic change in this fish was evidenced. In larval stage, they predominantly feed on microphytoplankton in the water column. Juvenile fish, transitional stage feeding both in water column and mangrove floor, feed on resuspended benthic diatom, zooplankton, benthos and detritus. Adult, feeding mainly in the midwater level and mangrove floor, with most diversed prey items ranging from microphytoplankton, protozoans, zooplankton, benthos and detritus. The latter two prey items greatly increased in adult diets. The ontogenetic differences in feeding habits have resulted from acquiring high energy diets to accompany growth and changes in the morphology of feeding structure and digestive system.

Morphological and histological study of digestive of spotted scat correlated to the trophic role of this fish. The development of digestive system, beginning from subterminal mouth confirmed that spotted scat were mainly benthic omnivore. In large fish, smaller and numerous teeth appeared on the maxilla and mandible in all sizes. Short gill rakers and U-shaped stomach with the pyloric appeared to be the important sites for lipid digestion allowing optimized absorption. The fundic portion has gastric glands increasing markedly with ages which secreting gastric juices. The ratio of intestinal length and standard length varied from 0.59-4.29. The villi on the intestinal walls increased markedly in the duodenum as the main absorptive site. The bile duct from the liver and gall bladder together with enzymes from the pancreas are all sent into the duodenum portion. Morphological and histological studies of the digestive system correlated to the relative importance of components in diets of each stage. Diatoms *Nitzschia* and *Pleurosigma/Gyrosigma* genera and cyanobacteria *Oscillatoria* spp. were the most common dietary components in each stage. Protozoan, zooplankton, benthos and detritus were also found in different proportions.

Prey selection in spotted scat of different stages followed the optimal foraging theory. Optimal prey size suitable to mouth gape that maximizes food consumed per unit capture, were choosen. Acquisition of diets also based on the nutritional quality and energy as revealed from the assimilation efficiency study. The role of spotted scat in Pak Phanang mangrove forest ecology classified as secondary consumers in the mangrove food webs sharing the same trophic levels with zooplankton feeders and benthic feeders.

Niche partitioning between spotted scat and tade mullet were shown by differences in feeding morphology and behavior, digestive system and seasonal shifts in relative importance of different components in diets. The study confirmed tade mullet were herbivore. Niche overlap in food items, mainly microphytoplankton and detritus, were evidenced in spotted scat and tade mullet diets.

## B. Rehabilitation and Management of Spotted Scat, *Scatophagus argus*

True resident fish species in the Pak Phanang mangrove forest comprised of 10 families namely Engraulidae, Clupeidae, Ambassidae, Leiognathidae, Gerreidae, Eleotridae, Gobiidae, Scatophagidae, Siganidae and Cynoglossidae. When compared with previous reports Sirimontaporn *et al*. (1997); Sirimontaporn (1998); Somkleeb *et al*. (2001); Sritakon *et al*. (2003); http://www.fishbase.org/search.php, the characteristic groups of fish common in the Pak Phanang Estuary were those fish that tolerated the environmental change such as low dissolved oxygen conditions and variable salinity regimes. These fish including *Scatophagus argus* were namely *Stolephorus insularis*, *Thryssa hamiltonii*, *Escualosa thoracata*, *Sardinella albella*, *Mystus gulio*, *Plotosus canius*, *Chelon permata*, *Neostethus lankesteri*, *Vespicula trachinoides*, *Sillago sihama*, *Dendrophysa russelli*, *Butis butis*, *Acentrogobius canius*, *Acentrogobius viridipunctatus*, *Parapocryptes serperaster*, *Pseudapocryptes lanceolatus*, *Stigmatogobius sadanundio*, *Taenioides cirratus*, *Siganus canaliculatus* and *Siganus javus*.

Flexibility in term of feeding and the physiological tolerance, allow spotted scat to survive in fluctuating environmental condition as experienced in estuaries. Macahilig *et al*. (1988) studied the salinity temperature and pH tolerance when spotted scat fry in ranging size from 2-4 g. The results of the salinity tolerance test indicated that spotted scat fry have a very wide salinity tolerance range (0-40 psu), and are more tolerant of transfers to lower salinities. Spotted scat acclimated at 25 psu tolerated transfer to 0 psu water, or a 25 psu salinity change, but when transferred to a higher salinity, the fish could only tolerate a change of less than 20 psu. This pattern of survival probably reflects an ability of the scat fry to better osmoregulate at lower osmotic pressures than in a hypersaline environment. This is true for many euryhaline fish. To maintain a constant internal environment at lower osmotic pressures, water entry and ion loss through the fish's exposed exchange surfaces, such as gut and gills, must be prevented. However, in the hypersaline environment, the fish must prevent water loss from its body and ion exchange from the external environment across the same exposed surfaces. The temperature tolerance test indicated the spotted scat fry showed a high temperature tolerance at the limit of 41.3 $^{o}$C as well as wide range of pH from 6-10. Due to these unique characteristics, spotted scat, *Scatophagus* *argus*, often recognized as indicator species of mangrove forests. They can be found in the natural mangrove forests, mangrove plantations and abandoned shrimp farms (Paphavasit *et al*., 2000; Ikejima *et al*., 2003; Tongnunui *et al*., 2007). Shinnaka *et al*. (2007) reported the recovery of the fish assemblage of *Scatophagus argus*, *Ambassis nalua*, *Chelon subviridis* and *Tetraodon nigroviridis* as related to mangrove reforestation in Pak Phanang Estuary.

From the fishery survey revealed the decline in spotted scat fish catch inside the bay both in term of abundance and size. The threats on fish species as suggested by Costello *et al*. (2002) include water quality, physical disturbance and hindrance to migration, reduction in suitable spawning areas and overfishing. Overfishing may play the important role in the declined fishery in the Pak Phanang Estuary as evidenced by the intensity and diversity of different fishing gear used in the area.

In order to protect the species, the habitat requires primary protection; subsequently, if this condition is met and the population is not taken to excess, then the species will be sustainably maintained. There is the need also to protect feeding and spawning grounds of the species. Pak Phanang Bay system is one of the richest and most diversed in term of fishery resources. Previously the estuary was lined with rich dense mangrove forests due to mangrove reforestation programs launched by the Royal Forestry Department. These mangrove forests served as nursery grounds, permanent habitats and breeding grounds as well as feeding grounds for fishery resources. Unplanned urban expansion and intensive shrimp farming in the Pak Phanang watershed in the past 25 years has resulted in the deteriorating environmental quality and degraded mangrove forests. Conflicts of interests in land use and saline water intrusion have led to the Royal-initiated Pak Phanang Basin Area Development Project, Nakhon Si Thammarat Province. His Majesty King Bhumibol suggested building a regulator with appurtenant structure in the area of Pak Phanang river mouth in order to prevent the intrusion of saline water and to retain freshwater in the water courses for the public use for agriculture and consumption. Digging of drainage canals discharging from the river was also envisaged to reduce the flood problem. The project has commenced in 1983. The dam was first operated in 1999. Prior to the dam construction, circulation and dispersion in the bay fluctuated in response to tides, river input and meteorological factors. The operation of the dam has disrupted the circulation and water exchange processes. Water quality is also affected in term of salinity changes and nutrient loadings. These environmental changes would have impact on the fishery resources. However, with the mangrove reforestation programs keeping paces with the environmental changes in the Pak Phanang Bay, the mangrove plantations were the important food sources habitats and nursery ground for fish of many commercial species.

Pak Phanang mangrove plantations also supported coastal fertility in food sources. Microphytoplankton, diatom and cyanobacteria, were most dominant groups. Zooplankton diversity dominated by arthropod crustaceans in both holoplankton and meroplankton. High organic content in sediment corresponded to the high organic detritus in form of underground, pneumatophore and seedling biomass in the mangrove plantations as compared to the natural mangrove forests. Dense tree canopy in the mangrove plantations contributed to this high organic detritus in term of forest biomass as the mangrove plantation aged. Theses organic detritus in turn will become the important food sources for aquatic species. However low diversity of benthos recorded in the mangrove plantations of Pak Phanang Estuary as previously reported by Paphavasit *et al*. (2004). This was due to the hypoxia condition in the Pak Phanang Bay and in the mangrove forests. Hypoxia condition in the area resulted from human activities in term of shrimp farmings and urbanization. Conversion of mangrove forests to shrimp farms, not only lead to degraded mangroves, but also change the hydrology of the area and increase sedimentation from shrimp farm effluents. Moreover the sedimentation rate in the Pak Phanang Estuary was quite rapid thus the exchange rate between the estuary and coastal seas occurred. Although the mangrove reforestation has been carried out since 1982, but the mangrove plantations were not maintained in the silviculture technique to promote production. Thinning and pruning have not been carried out. In the long term, even with high forest biomass as the mangrove plantation aged, but these hypoxia conditions are not suitable for benthos and fish. The availability of habitats and food sources will soon be lost.

Therefore, Pak Phanang mangrove should be maintained in the silviculture technique such as trimming the branches occasionally for sunlight through the ground to accelerate decompose detritus and increase in subcanopy light transmission. Forest management are require to promote mangrove forest productivity such as tree thinning to reduce tree mortality and enhance seedling production when properly conducted. Selective pruning can stimulate an increase in net primary productivity by inducing the development of new sprouts in most species of mangrove trees with the exception of the species *Rhizophora*. This species loses the ability to produce reserve meristem within two or three years and therefore new sprouts will not develop from pruned branches >2.5 cm in diameter. This unique pruning response is one of the principle reasons regulated mechanical alteration of mangroves along shorelines (Parkinson *et al*., 1999).

In addition to determine the need for protection and management of the species, it is necessary to determine both the size and structure of the populations. Thus population dynamics and structure of spotted scat in the Pak Phanang Bay is recommended. The present study concentrated only on the distribution of spotted scats in relation to mangrove forests as feeding ground. The population dynamics would provide the data on variable population, maintenance of spawners, reproductive biology and recruitments. Management measures can be drawn from this population dynamic study. Releasing of spotted scat larvae and fry into the Pak Phanang Bay enhancing fishery production should be incorporated into the mangrove rehabilitation program.

## C. Promoting *Scatophagus argus* as Aquaculture Species

Spotted scat has long been recognized as one of the economically important fish in the mangrove forests in Thailand in particular in Nakhon Si Thammarat and Songkhla Provinces. But the culture of this fish species is limited. Spotted scat has demonstrated several outstanding attribute for a cultured species. They are highly tolerant of the environmental changes in particular salinity, temperature and pH. Due to the high upper salinity and temperature tolerance limits, the spotted scat can survive in culture ponds even when temperatures and salinities reach high values during the summer months (Macahilig *et al*., 1988). The spotted scat also tolerated low dissolved oxygen concentration as revealed from the same experiment. Spotted scat should be promoted as aquaculture species as the supplementary income for the coastal communities in Pak Phanang.

At present, the National Institute of Coastal Aquaculture (NICA), Department of Fishery, has demonstrated some success in promoting the spotted scat culture through artificial semination. The Department of Fishery has already incorporated the release of spotted scat fry into Songkhla Lake in the attempt to enhance fishery production. They also encourage the culture of this fish species. Low survival rate resulted from the early time at hatching as reported by NICA corresponded to the work of Barry and Fast (1988). From their study in the early larval development of spotted scat found the eyes, mouth and gut became functional 2-3 days after hatching. Feeding behavior was apparent when larvae collected at the surface, along the sides and corners of the tank, 3 day after hatching. Mortalities increased in frequency a day later, probably because of starvation. Thus adequate feed and appropriate food for larvae should be prepared. From the feeding ecology of spotted scat larvae, it is recommended that single-cell microphytoplankton which in nutritional such as pennate diatoms, *Chaetoceros* sp., *Nitzschia* sp.

should be provided in abundance for first feeding larvae. Rotifers should be used as food in later stage. Mix food items, microphytoplankton and macrozooplankton such as shrimp larvae, served as the suitable food sources for late larvae.

Water quality control and monitoring are important in spotted scat culture. Although from Macahilig *et al*. (1988) study showed a very wide salinity tolerance range (0-40 psu), in spotted scat fry. When transferred to a higher salinity, the fish could only tolerate a change of less than 20 psu. This pattern of survival probably reflects an ability of the scat fry to osmoregulate better at lower osmotic pressures than in a hypersaline environment. Spotted scat must increase their metabolic rates and oxygen consumption to actively pump ions out of their bodies when attempting to osmoregulate at higher salinities. As a result, the gills are exposed to an even greater extent to the external medium which increases the rate of passive ion and water exchange across the gill membranes. Metabolic processes are also stimulated directly by the increase in temperature, which further increases oxygen demand. Thus, an upper limit at which the fish can no longer effectively eliminate ion entry and water loss is soon reached at elevated temperatures and salinities. In a pond situation, however, dissolved oxygen concentrations can reach very low levels during grow out. The spotted scat may be able to tolerate low dissolved oxygen concentration. Therefore, oxygen concentrations were always maintained throughout the culture by constant aeration.

## D. Stress Indicators-Living in Stressful Environment

Although spotted scat, *Scatophagus argus*, being the estuarine tolerance species with flexibility in feeding and physiological tolerance, the histological study revealed several indication which may arisen from living in stressful environment or sublethal effect. Habitat utilization of spotted scat in mangrove forest was controlled by environmental parameters and mangrove forest characteristics. Fish were exposed to stress from handling, transport and acclimation in their natural habitat such as poor water quality and external and internal parasite. Fish gills are among the most delicate structures. Their vulnerability is thus considerable because their external location and necessarily intimate contact with the water means that they are liable to damage by any irritant materials, whether dissolved or suspended, in the water. The gills are also, by their nature, sites with a good supply of nutrients and relative safety of location and so are a favorured site for external protozoan and monogenean trematode parasites. Because of its relative simplicity of structure only a limited number of reactions can be manifested by the diseased gill.

External irritants are the most frequent causes of significant gill pathological change. Stress from water quality such as changes in dissolved oxygen and salinity as well as pollutant may affected gill structure and respiratory physiology of spotted scat under normal and hypoxia condition. Diffusing capacity of the gills is reduced following the action of effect and consequently there is a fall in the oxygen supply to the tissue. Lethality was a consequence of respiratory stress due to the decreased oxygen diffusion capacity of the gills. Figure 6.1 showed most gill lamellae appeared histological normal, except for moderate swelling of some lamellar epithelial cell. This is one of very few investigations in this species which attempt to examine the responses of fish to two or more simultaneous stresses. This is clearly an area for future research.


Figure 6.1 The secondary gill lamellae of adult spotted scat swelling (arrow); H&E.

Fish are hosts to a large number of protozoans and macroparasites. The effects of infection or infestation may range from being undetectable to causing the death of the host. Sublethal effects including decrease in growth or impair reproduction, energy budget of the host, causing sensory impairment, changed swimming behavior, morphological deformation, liver and cardiac damage and skin erosion. Even if the parasites do not directly cause the death of the fish, they make the fish less able to survive in unfavorable environmental condition (Wootton, 1999). From the histological results, *Henneguya* sp. cysts adhered to the gill epithelium of spotted scat (Figure 6.2)

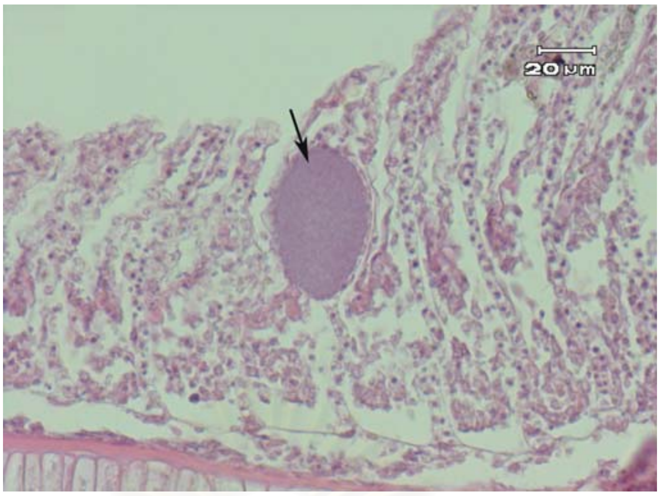



Figure 6.2 Hyperplasia and displacement of the respiratory epithelium of spotted scat embeded with cysts of *Henneguya* sp. (arrow); H&E.

It was evidenced from several culture systems that the stress probably contributed to the mortalities in the populations of spotted scat. During culture system, the fish were exposed to stress from acclimation to the fluctuated environment. These stress factors may have resulted in physiological disturbances, the consequences of which could have adversely affected the whole fish stock either directly, on indirectly, by rendering the fish susceptible to opportunistic organisms. The spotted scat easily becomes infected when reared in poor water quality and intensive culture system. In these conditions, parasites were found the surface of the gill such as the *Henneguya* sp. and *Trichodinella* sp. Chinabut (1980) surveyed on parasites in sand goby in natural waters and found that the prevalence of infection by *Henneguya* sp. reached 84%; in some cases 600 cysts/fish were observed. In addition, Martins *et al.* (1997) reported infections of *Henneguya leporinicola* in the gills of pacu fish, *Piaractus mesopotamicus* that caused severe mortality. The histological studies showed petechiaetion, excessive mucus production, severe inflammatory foci and hyperplasia in the gill epithelium. The inter and intralamellar presence of cysts associated to hyperplasia and inflammation increased the adherence between secondary lamellae. The hyperplasia of the goblet cells associated with an increase in the mucus production caused respiratory distress syndrome and suffocation of fish. The lesions were similar to those observed in *Henneguya* infections in perch, *Perca fluviatilis* (Dyková and Lom, 1978).

*Trichodinella* sp. was also found in gills (Figure 6.3). Trichodinids did not occur in large numbers on a healthy fish and hence the irritation caused by the attachment of their adhesive discs is quite negligible. Trichodinids can affect cultured fish during nursery and grow-out phase.

Affected fish show excessive mucus production on the body surface and gills with frayed fins and pale gills. Heavily infected fish rub their body against objects. Fish are weak during heavy infection. Lio-Po and Barry (1988) reported on *Trichodina* sp., parasites, in the gill of adult spotted scat with an average weight of 150 g were initially stocked in brackish water in canvas tank. The gills appeared normal expect for some occasional areas of secondary lamellar hyperplasia. The summary of the parasite load of spotted scat is shown in Table 6.1.

Table 6.1 Summary of parasites observed in the spotted scat (Lio-Po and Barry, 1988)

| **Parasite** | **Parasite load** | **Organ affected** |
|---|---|---|
| *Amyloodinium* sp. | Occasional to heavy | Gills |
| *Caligus* sp. | Occasional to heavy | Gills and skin |
| *Microsporidia* | Moderate to heavy | Intestine |
| *Trichodina* sp. | Occasional | Gills |
| Monogenean trematode | Occasional | Gills |
| Isopod | Occasional | Mouth/gills |

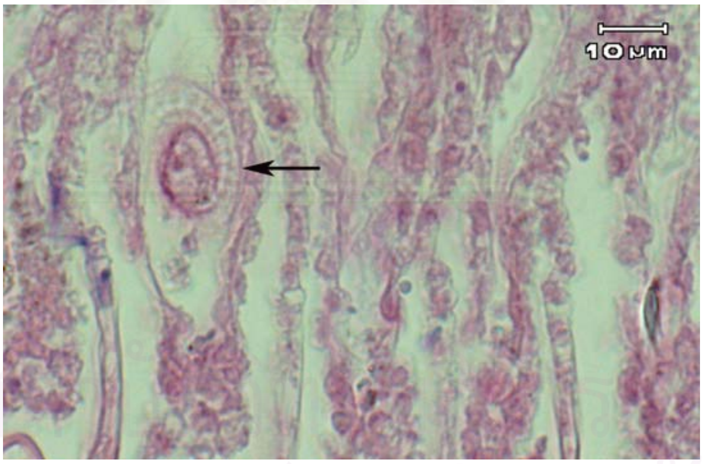



Figure 6.3 Histological section through the gill of spotted scat with trichodinid infestation (arrow); H&E.

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# APPENDICES

# APPENDIX I

## IMPORTANCE OF PAK PHANANG MANGROVE FOREST FOR FISH COMMUNITIES

Appendix 1.1 Fishery questionnaires

Fishery Questionnaires in Pak Phanang Estuary

Date…………………………................

Present address………………………………………………………………………………

Fishing area……………………………………………………………………………………

Habitat characteristics…………………………………………………………………………

Time when fishing begin ……………………... Time when fishing end………………………...

Number of fishing day per week ………………………………………………………………

Fishing labor hired/time…..……………………………………………………………person

Wage paid for labour (baht /day)…......……….. Number of day employed ……………………..

Size of boat : length ………………………...m. Size of engine …….………………horsepower

Mark ☑ on fishing gears used. Marked as many as used.

| Fishing gear | Gill net | Push net | Trawl net | Fish hook | Fishing stakes | Net | Other |
|---|---|---|---|---|---|---|---|
| Number | | | | | | | |
| Mesh size (cm.) | | | | | | | |

Fish species were found………………………………………………………………………..

Dominant fish species……………………………………………………………………........

Total catch (kg./time)…………………………………………..………..……………..

Income (baht/day)……………………………………………………………………………...

Spawning area…………………………………………………………………………….....

Duration of spawning season……………………………………………………………………

Opinion of total catch ☐ increase ☐ decrease

Reason for the changes in total catch

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Spotted scat fisheries in Pak Phanang Bay

Total catch of spotted scat……………..………………………………...……….……...individuals

Total weight……………………………………………..…………………………..……kg.

Average size of spotted scat were catched (in total length)..……………………...…………….cm.

| Identify | Male | Female |
|---|---|---|
| Color | | |
| Shape | | |
| Length | | |
| Weight | | |

Remark…………………………………………………………..……………………………..

..………………………………………………………………………………………………...

…………………………………………………………………………………………………

| | | |
|---|---|---|
| Sex ratio | Month where Female>Male | |
| | Month where Male>Female | |
| | Month where Male=Female | |

Size of female fish with eggs………...…….cm.  Weight………………………………………g.

Duration of spawning season:…………..…………………………………………………...

Spawning area…………………………………………………………………………….....

Months recorded for high density of spotted scat…………………………………………...

| Total catch of spotted scat/day | Size (cm.) | Number (kg.) |
|---|---|---|
| Klong Bang Hua Koo | | |
| Klong Bang Luk | | |
| Klong Gong Kong | | |
| Mangrove plantation in year 1981 | | |
| Mangrove plantation in year 1987 | | |
| Bang Yai | | |
| Estuarine waterways | | |
| Laem  Talumpuk | | |
| Buoy number………. | | |

Behavior found in school ☐ swim as individual fish ☐

Smallest size recorded ……………………...........................................................................cm.

Common habitat…………………………………………………………………………...…...

Month of high density ……………………………………………………………………………

Habitat characteristic……………………………………………………………………………...

Feeding in spotted scat – mark ☑ on the food you think spotted scat eat

| Prey items | Detritus | Fish | Plant/algae | Benthos | Other |
|---|---|---|---|---|---|
| Fish larvae size……………cm. | | | | | |
| Large fish size……..………cm. | | | | | |

General data in Pak Phanang Bay

Duration of wet season……………………………………………………………………………

Heavy rain in month………………………………………………………………………………

Salinity intrusion in the Pak Phanang Bay

Irrigation regulator ☐ Pak Phanang market ☐ Shrimp landing ☐

Other (specify) ……………………………………………………………………………………

Source of fresh water (Klong)

……………………………………………………………………………………………………

…………………………………………………………………………………………………..…

Dry season…………………………………………………………………………………………...

Drought in month…………………………………………………………………………………

Salinity reach to area

Irrigation regulator ☐ Pak Phanang market ☐ Shrimp landing ☐

Other (specify) ……………………………………………………………………………………

Source of fresh water (Klong)

……………………………………………………………………………………………………

…………………………………………………………………………………………………..…

Status of fishery prior to the construction of irrigation regulator (before 1999)

Fishing area……………………………………………………………………………………….

Habitat characteristics…………………………………………………………………………….

Time when fishing begin ……………………... Time when fishing end………………………...

Number of fishing day per week …………………………………………………………………

Fishing labor hired/time…..………………………………………………………………person

Wage paid for labour (baht /day)…......……….. Number of day employed ……………………..

Size of boat : length ………………………...m. Size of engine …….………………horsepower

Mark ☑ on fishing gears used. Marked as many as used.

| Fishing gear | Gill net | Push net | Trawl net | Fish hook | Fishing stakes | Net | Other |
|---|---|---|---|---|---|---|---|
| Number | | | | | | | |
| Mesh size (cm.) | | | | | | | |

Fish species were found…………………………………………………………………………..

Dominant fish species……………………………………………………………………........

Total catch (kg./time)…………………………………………….………..………….………….

Income (baht/day)……………………………………………………………………………...

Spawning area……………………………………………………………………………….....

Duration of spawning season……………………………………………………………………

| Total catch of fish/day | Size (cm.) | Number (kg.) |
|---|---|---|
| Klong Bang Hua Koo | | |
| Klong Bang Luk | | |
| Klong Gong Kong | | |
| Mangrove plantation in year 1981 | | |
| Mangrove plantation in year 1987 | | |
| Bang Yai | | |
| Estuarine waterways | | |
| Laem Talumpuk | | |
| Buoy number……….. | | |

Opinion of total catch ☐ increase ☐ decrease

Reason for the changes in total catch…………………………………………………..................

……………………………………………….............................................................................

Status of fishery after the construction of irrigation regulator (within 4 years)

Fishing area……………………………………………………………………………………….

Habitat characteristics…………………………………………………………………………….

Time when fishing begin ……………………...    Time when fishing end………………………...

Number of fishing day per week …………………………………………………………………

Fishing labor hired/time…..……………………………………………………………person

Wage paid for labour (baht /day)…......………..    Number of day employed ……………………..

Size of boat : length ………………………...m.    Size of engine …….………………horsepower

Mark ☑ on fishing gears used. Marked as many as used.

| Fishing gear | Gill net | Push net | Trawl net | Fish hook | Fishing stakes | Net | Other |
|---|---|---|---|---|---|---|---|
| Number | | | | | | | |
| Mesh size (cm.) | | | | | | | |

Fish species were found……………………………………………………………………..

Dominant fish species……………………………………………………………………..........

Total catch (kg./time)…………………………………………….………..………….…………..

Income (baht/day)…………………………………………………………………………….....

Spawning area……………………………………………………………………………….......

Duration of spawning season…………………………………………………………………

| Total catch of fish/day | Size (cm.) | Number (kg.) |
|---|---|---|
| Klong Bang Hua Koo | | |
| Klong Bang Luk | | |
| Klong Gong Kong | | |
| Mangrove plantation in year 1981 | | |
| Mangrove plantation in year 1987 | | |
| Bang Yai | | |
| Estuarine waterways | | |
| Laem Talumpuk | | |
| Buoy number……….. | | |

Opinion of total catch ☐ increase ☐ decrease

Reason for the changes in total catch………………………………………………...................

……………………………………………….........................................................................

Appendix 1.2 ANOVA test of environmental parameters between months in high salinity

| Environmental parameters | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Salinity (psu) | Between Groups | 320.527 | 2 | 160.263 | 2.848 | 0.110 |
| | Within Groups | 506.410 | 9 | 56.268 | | |
| | Total | 826.937 | 11 | | | |
| Temperature ($^{o}$C) | Between Groups | 131.355 | 2 | 65.678 | 0.858 | 0.456 |
| | Within Groups | 689.228 | 9 | 76.581 | | |
| | Total | 820.583 | 11 | | | |
| DO (mg./l) | Between Groups | 8.422 | 2 | 4.211 | 1.550 | 0.264 |
| | Within Groups | 24.455 | 9 | 2.717 | | |
| | Total | 32.877 | 11 | | | |
| pH | Between Groups | 11.012 | 2 | 5.506 | 1.206 | 0.344 |
| | Within Groups | 41.105 | 9 | 4.567 | | |
| | Total | 52.117 | 11 | | | |
| Transparency (m.) | Between Groups | 0.015 | 2 | 0.007 | 0.365 | 0.704 |
| | Within Groups | 0.185 | 9 | 0.021 | | |
| | Total | 0.200 | 11 | | | |
| Depth (m.) | Between Groups | 5.315 | 2 | 2.658 | 1.934 | 0.200 |
| | Within Groups | 12.368 | 9 | 1.374 | | |
| | Total | 17.683 | 11 | | | |

Appendix 1.3 Independent sample *t*-test of environmental parameters between months in high and low salinity

| **Environmental parameters** | | **Levene's Test for Equality of Variances** | | **t-test for Equality of Means** | | |
|---|---|---|---|---|---|---|
| | | **F** | **Sig.** | **t** | **df** | **Sig.(2-tailed)** |
| Salinity (psu) | Equal variances assumed | 0.846 | 0.373 | -5.014 | 14 | 0.000* |
| | Equal variances not assumed | | | -8.132 | 13.898 | 0.000 |
| Temperature ($^{o}$C) | Equal variances assumed | 2.171 | 0.163 | -1.024 | 14 | 0.323 |
| | Equal variances not assumed | | | -0.792 | 3.765 | 0.475 |
| DO (mg./l) | Equal variances assumed | 0.406 | 0.534 | -2.655 | 14 | 0.019* |
| | Equal variances not assumed | | | -3.112 | 7.093 | 0.017 |
| pH | Equal variances assumed | 2.008 | 0.178 | -1.058 | 14 | 0.308 |
| | Equal variances not assumed | | | -0.826 | 3.798 | 0.458 |
| Transparency (m.) | Equal variances assumed | 0.085 | 0.774 | -1.271 | 14 | 0.224 |
| | Equal variances not assumed | | | -1.239 | 4.969 | 0.271 |
| Depth (m.) | Equal variances assumed | 0.513 | 0.485 | -0.859 | 14 | 0.405 |
| | Equal variances not assumed | | | -1.200 | 11.252 | 0.255 |

Remark: * The mean difference is significant at the 0.05 level

# APPENDIX II

## FEEDING ECOLOGY IN SPOTTED SCAT, *Scatophagus argus*

Appendix 2.1 Feeding morphological data sheet of fish

**Morphological data sheet**

**Fish species……………………………………………Collected from……..……………………………………….. Date………………………………………**

| No. | Total length (cm.) | Weight (g.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Intestine length (cm.) | Numer of Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
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Appendix 2.2 ANOVA test of food components of spotted scat larvae between months in high salinity

| Prey items | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Cyanophyceae | Between Groups | 0.022 | 2 | 0.011 | 0.245 | 0.790 |
| | Within Groups | 0.264 | 6 | 0.044 | | |
| | Total | 0.285 | 8 | | | |
| Bacillariophyceae | Between Groups | 0.009 | 2 | 0.005 | 0.421 | 0.675 |
| | Within Groups | 0.068 | 6 | 0.011 | | |
| | Total | 0.077 | 8 | | | |
| Dinophyceae | Between Groups | 2.635 | 2 | 1.318 | 4.160 | 0.074 |
| | Within Groups | 1.901 | 6 | 0.317 | | |
| | Total | 4.536 | 8 | | | |
| Protozoa | Between Groups | 0.508 | 2 | 0.254 | 1.345 | 0.329 |
| | Within Groups | 1.133 | 6 | 0.189 | | |
| | Total | 1.641 | 8 | | | |
| Zooplankton | Between Groups | 1.234 | 2 | 0.617 | 0.588 | 0.585 |
| | Within Groups | 6.299 | 6 | 1.050 | | |
| | Total | 7.532 | 8 | | | |
| Benthos | Between Groups | 0.743 | 2 | 0.371 | 1.596 | 0.278 |
| | Within Groups | 1.396 | 6 | 0.233 | | |
| | Total | 2.138 | 8 | | | |
| Detritus | Between Groups | 1.002 | 2 | 0.501 | 2.687 | 0.147 |
| | Within Groups | 1.118 | 6 | 0.186 | | |
| | Total | 2.120 | 8 | | | |

Appendix 2.3 Independent sample *t-test* of food components of spotted scat larvae between high and low salinity

| Prey items | | Levene's Test for | | t-test for Equality of Means | | |
|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig.(2-tailed) |
| Cyanophyceae | Equal variances assumed | 2.330 | 0.158 | 0.381 | 10 | 0.711 |
| | Equal variances not assumed | | | 0.282 | 2.442 | 0.800 |
| Bacillariophyceae | Equal variances assumed | 1.412 | 0.262 | 0.915 | 10 | 0.382 |
| | Equal variances not assumed | | | 0.715 | 2.554 | 0.534 |
| Dinophyceae | Equal variances assumed | 0.007 | 0.937 | -0.248 | 9 | 0.809 |
| | Equal variances not assumed | | | -0.218 | 1.327 | 0.856 |
| Protozoa | Equal variances assumed | 0.509 | 0.492 | -1.210 | 10 | 0.254 |
| | Equal variances not assumed | | | -1.695 | 7.652 | 0.130 |
| Zooplankton | Equal variances assumed | 0.137 | 0.719 | -0.584 | 10 | 0.572 |
| | Equal variances not assumed | | | -0.648 | 4.184 | 0.551 |
| Benthos | Equal variances assumed | 3.963 | 0.075 | 0.943 | 10 | 0.368 |
| | Equal variances not assumed | | | 0.650 | 2.315 | 0.574 |
| Detritus | Equal variances assumed | 5.650 | 0.039 | -0.913 | 10 | 0.383 |
| | Equal variances not assumed | | | -1.316 | 8.289 | 0.223 |

Appendix 2.4 ANOVA test of food components of juvenile spotted scat between months in high salinity

| **Prey items** | | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|---|
| Cyanophyceae | Between Groups | 2.317 | 2 | 1.158 | 3.476 | 0.113 |
| | Within Groups | 1.666 | 5 | 0.333 | | |
| | Total | 3.983 | 7 | | | |
| Bacillariophyceae | Between Groups | 0.173 | 2 | 0.087 | 2.859 | 0.149 |
| | Within Groups | 0.151 | 5 | 0.030 | | |
| | Total | 0.325 | 7 | | | |
| Dinophyceae | Between Groups | 0.803 | 2 | 0.402 | 0.327 | 0.739 |
| | Within Groups | 4.916 | 4 | 1.229 | | |
| | Total | 5.719 | 6 | | | |
| Protozoa | Between Groups | 0.672 | 2 | 0.336 | 1.152 | 0.388 |
| | Within Groups | 1.459 | 5 | 0.292 | | |
| | Total | 2.132 | 7 | | | |
| Zooplankton | Between Groups | 2.079 | 2 | 1.039 | 1.158 | 0.386 |
| | Within Groups | 4.487 | 5 | 0.897 | | |
| | Total | 6.566 | 7 | | | |
| Benthos | Between Groups | 0.159 | 2 | 0.079 | 0.272 | 0.773 |
| | Within Groups | 1.459 | 5 | 0.292 | | |
| | Total | 1.617 | 7 | | | |
| Arthropoda | Between Groups | 0.001 | 1 | 0.001 | 0.005 | 0.954 |
| | Within Groups | 0.099 | 1 | 0.099 | | |
| | Total | 0.099 | 2 | | | |
| Detritus | Between Groups | 0.612 | 2 | 0.306 | 0.692 | 0.543 |
| | Within Groups | 2.213 | 5 | 0.443 | | |
| | Total | 2.825 | 7 | | | |

Appendix 2.5 Independent sample *t-test* of food components of juvenile spotted scat between high and low salinity

| **Prey items** | | **Levene's Test for** | | **t-test for Equality of Means** | | |
|---|---|---|---|---|---|---|
| | | **F** | **Sig.** | **t** | **df** | **Sig.(2-tailed)** |
| Cyanophyceae | Equal variances assumed | 4.653 | 0.059 | -1.063 | 9 | 0.315 |
| | Equal variances not assumed | | | -1.731 | 8.048 | 0.121 |
| Bacillariophyceae | Equal variances assumed | 0.144 | 0.713 | 0.693 | 9 | 0.506 |
| | Equal variances not assumed | | | 0.891 | 6.644 | 0.404 |
| Dinophyceae | Equal variances assumed | 3.095 | 0.117 | 0.023 | 8 | 0.982 |
| | Equal variances not assumed | | | 0.030 | 7.200 | 0.977 |
| Protozoa | Equal variances assumed | 0.945 | 0.356 | 0.627 | 9 | 0.546 |
| | Equal variances not assumed | | | 0.884 | 8.338 | 0.401 |
| Zooplankton | Equal variances assumed | 2.033 | 0.188 | 0.742 | 9 | 0.477 |
| | Equal variances not assumed | | | 1.090 | 8.871 | 0.304 |
| Benthos | Equal variances assumed | 0.032 | 0.863 | 0.680 | 9 | 0.514 |
| | Equal variances not assumed | | | 0.698 | 3.819 | 0.525 |
| Detritus | Equal variances assumed | 1.726 | 0.221 | -2.158 | 9 | 0.059 |
| | Equal variances not assumed | | | -3.205 | 8.949 | 0.011 |

Appendix 2.6 ANOVA test of food components of adult spotted scat between months in high salinity

| Prey items | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Cyanophyceae | Between Groups | 3.401 | 2 | 1.700 | 7.276 | 0.121 |
| | Within Groups | 0.467 | 2 | 0.234 | | |
| | Total | 3.868 | 4 | | | |
| Bacillariophyceae | Between Groups | 0.087 | 2 | 0.043 | 15.774 | 0.060 |
| | Within Groups | 0.006 | 2 | 0.003 | | |
| | Total | 0.093 | 4 | | | |
| Protozoa | Between Groups | 1.415 | 2 | 0.707 | 1.321 | 0.431 |
| | Within Groups | 1.071 | 2 | 0.535 | | |
| | Total | 2.486 | 4 | | | |
| Zooplankton | Between Groups | 0.262 | 2 | 0.131 | 0.283 | 0.779 |
| | Within Groups | 0.925 | 2 | 0.462 | | |
| | Total | 1.187 | 4 | | | |
| Benthos | Between Groups | 1.461 | 2 | 0.731 | 2.182 | 0.314 |
| | Within Groups | 0.670 | 2 | 0.335 | | |
| | Total | 2.131 | 4 | | | |
| Detritus | Between Groups | 1.240 | 2 | 0.620 | 0.785 | 0.560 |
| | Within Groups | 1.579 | 2 | 0.790 | | |
| | Total | 2.819 | 4 | | | |

Appendix 2.7 Independent sample *t-test* of food components of adult spotted scat between high and low salinity

| **Prey items** | | **Levene's Test for** | | **t-test for Equality of Means** | | |
|---|---|---|---|---|---|---|
| | | **F** | **Sig.** | **t** | **df** | **Sig.(2-tailed)** |
| Cyanophyceae | Equal variances assumed | 0.123 | 0.736 | 0.163 | 7 | 0.875 |
| | Equal variances not assumed | | | 0.160 | 5.936 | 0.878 |
| Bacillariophyceae | Equal variances assumed | 9.006 | 0.020 | 0.966 | 7 | 0.366 |
| | Equal variances not assumed | | | 0.851 | 3.065 | 0.456 |
| Protozoa | Equal variances assumed | 1.439 | 0.269 | 0.121 | 7 | 0.907 |
| | Equal variances not assumed | | | 0.111 | 4.049 | 0.917 |
| Zooplankton | Equal variances assumed | 6.474 | 0.038 | 0.050 | 7 | 0.962 |
| | Equal variances not assumed | | | 0.047 | 4.784 | 0.964 |
| Benthos | Equal variances assumed | 0.000 | 0.991 | 1.108 | 7 | 0.304 |
| | Equal variances not assumed | | | 1.108 | 6.556 | 0.307 |
| Detritus | Equal variances assumed | 0.278 | 0.614 | 1.249 | 7 | 0.252 |
| | Equal variances not assumed | | | 1.237 | 6.328 | 0.260 |

Appendix 2.8 Independent sample *t-test* of food components of spotted scat between mangrove forests and estuarine waterways

| **Prey items** | | **Levene's Test for** | | **t-test for Equality of Means** | | |
|---|---|---|---|---|---|---|
| | | **F** | **Sig.** | **t** | **df** | **Sig.(2-tailed)** |
| Cyanophyceae | Equal variances assumed | 16.646 | 0.005 | 1.511 | 7 | 0.175 |
| | Equal variances not assumed | | | 1.703 | 4.241 | 0.160 |
| Bacillariophyceae | Equal variances assumed | 4.893 | 0.063 | 1.073 | 7 | 0.319 |
| | Equal variances not assumed | | | 1.216 | 4.013 | 0.291 |
| Protozoa | Equal variances assumed | 0.203 | 0.666 | -1.216 | 7 | 0.263 |
| | Equal variances not assumed | | | -1.167 | 5.308 | 0.293 |
| Zooplankton | Equal variances assumed | 0.886 | 0.378 | 0.305 | 7 | 0.769 |
| | Equal variances not assumed | | | 0.295 | 5.570 | 0.779 |
| Benthos | Equal variances assumed | 0.024 | 0.881 | -1.700 | 7 | 0.133 |
| | Equal variances not assumed | | | -1.711 | 6.714 | 0.133 |
| Detritus | Equal variances assumed | 0.035 | 0.857 | 0.446 | 7 | 0.669 |
| | Equal variances not assumed | | | 0.443 | 6.406 | 0.672 |

Appendix 2.9 ANOVA test of food components of three stages in mangrove forests between low and high salinity

| Prey items | | Sum of Squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| Cyanophyceae | Between Groups | 0.017 | 2 | 0.008 | 0.761 | 0.540 |
| | Within Groups | 0.033 | 3 | 0.011 | | |
| | Total | 0.050 | 5 | | | |
| Bacillariophyceae | Between Groups | 0.002 | 2 | 0.001 | 0.355 | 0.727 |
| | Within Groups | 0.009 | 3 | 0.003 | | |
| | Total | 0.012 | 5 | | | |
| Protozoa | Between Groups | 0.091 | 2 | 0.046 | 411.086 | 0.000* |
| | Within Groups | 0.000 | 3 | 0.000 | | |
| | Total | 0.091 | 5 | | | |
| Zooplankton | Between Groups | 0.060 | 2 | 0.030 | 0.382 | 0.712 |
| | Within Groups | 0.236 | 3 | 0.079 | | |
| | Total | 0.296 | 5 | | | |
| Benthos | Between Groups | 0.604 | 2 | 0.302 | 18.873 | 0.020* |
| | Within Groups | 0.048 | 3 | 0.016 | | |
| | Total | 0.652 | 5 | | | |
| Detritus | Between Groups | 0.439 | 2 | 0.219 | 1.944 | 0.287 |
| | Within Groups | 0.339 | 3 | 0.113 | | |
| | Total | 0.777 | 5 | | | |

Remark: * The mean difference is significant at the 0.05 level

## Post Hoc Tests

**Multiple Comparisons**

Tukey HSD

| Dependent Variable | (I) size | (J) size | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| Cyanophyceae | Larvae | Juvenile | .03776 | .10513 | .933 | -.4016 | .4771 |
| | | Adults | .12634 | .10513 | .529 | -.3130 | .5657 |
| | Juvenile | Larvae | -.03776 | .10513 | .933 | -.4771 | .4016 |
| | | Adults | .08858 | .10513 | .707 | -.3507 | .5279 |
| | Adults | Larvae | -.12634 | .10513 | .529 | -.5657 | .3130 |
| | | Juvenile | -.08858 | .10513 | .707 | -.5279 | .3507 |
| Bacillariophyceae | Larvae | Juvenile | -.02905 | .05607 | .868 | -.2633 | .2052 |
| | | Adults | .01777 | .05607 | .947 | -.2165 | .2521 |
| | Juvenile | Larvae | .02905 | .05607 | .868 | -.2052 | .2633 |
| | | Adults | .04681 | .05607 | .711 | -.1875 | .2811 |
| | Adults | Larvae | -.01777 | .05607 | .947 | -.2521 | .2165 |
| | | Juvenile | -.04681 | .05607 | .711 | -.2811 | .1875 |
| Protozoa | Larvae | Juvenile | .16464* | .01052 | .001 | .1207 | .2086 |
| | | Adults | .30134* | .01052 | .000 | .2574 | .3453 |
| | Juvenile | Larvae | -.16464* | .01052 | .001 | -.2086 | -.1207 |
| | | Adults | .13670* | .01052 | .002 | .0927 | .1807 |
| | Adults | Larvae | -.30134* | .01052 | .000 | -.3453 | -.2574 |
| | | Juvenile | -.13670* | .01052 | .002 | -.1807 | -.0927 |
| Zooplankton | Larvae | Juvenile | -.10008 | .28034 | .934 | -1.2716 | 1.0714 |
| | | Adults | .14363 | .28034 | .871 | -1.0278 | 1.3151 |
| | Juvenile | Larvae | .10008 | .28034 | .934 | -1.0714 | 1.2716 |
| | | Adults | .24372 | .28034 | .693 | -.9278 | 1.4152 |
| | Adults | Larvae | -.14363 | .28034 | .871 | -1.3151 | 1.0278 |
| | | Juvenile | -.24372 | .28034 | .693 | -1.4152 | .9278 |
| Benthos | Larvae | Juvenile | -.17253 | .12646 | .459 | -.7010 | .3559 |
| | | Adults | -.74232* | .12646 | .020 | -1.2708 | -.2139 |
| | Juvenile | Larvae | .17253 | .12646 | .459 | -.3559 | .7010 |
| | | Adults | -.56979* | .12646 | .041 | -1.0982 | -.0413 |
| | Adults | Larvae | .74232* | .12646 | .020 | .2139 | 1.2708 |
| | | Juvenile | .56979* | .12646 | .041 | .0413 | 1.0982 |
| Detritus | Larvae | Juvenile | -.50776 | .33595 | .402 | -1.9116 | .8961 |
| | | Adults | -.62241 | .33595 | .295 | -2.0263 | .7814 |
| | Juvenile | Larvae | .50776 | .33595 | .402 | -.8961 | 1.9116 |
| | | Adults | -.11465 | .33595 | .939 | -1.5185 | 1.2892 |
| | Adults | Larvae | .62241 | .33595 | .295 | -.7814 | 2.0263 |
| | | Juvenile | .11465 | .33595 | .939 | -1.2892 | 1.5185 |

*. The mean difference is significant at the .05 level.

Appendix 2.10 ANOVA test of carbon and nitrogen ratio from stomach content in three stages of spotted scat

| C/N ratio | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 0.071 | 2 | 0.035 | 3.016 | 0.057 |
| Within Groups | 0.668 | 57 | 0.012 | | |
| Total | 0.738 | 59 | | | |

Appendix 2.11 Morphological data of spotted scat larvae collected from mangrove forests in Pak Phanang Estuary, Nakhon Si Thammarat Province

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.77 | 1.27 | 0.83 | 0.64 | 0.14 | 2 | 15 | 8 | 0.11 |
| 2 | 1.69 | 1.27 | 0.79 | 0.63 | 0.13 | 2 | 14 | 8 | 0.12 |
| 3 | 1.47 | 1.09 | 0.71 | 0.54 | 0.09 | 1 | 15 | 12 | 0.13 |
| 4 | 1.84 | 1.36 | 0.86 | 0.70 | 0.16 | 3 | 15 | 10 | 0.13 |
| 5 | 1.69 | 1.28 | 0.82 | 0.63 | 0.13 | 2 | 15 | 10 | 0.11 |
| 6 | 1.37 | 0.99 | 0.67 | 0.51 | 0.07 | 1 | 16 | 10 | 0.11 |
| 7 | 1.53 | 1.12 | 0.72 | 0.55 | 0.10 | 2 | 15 | 11 | 0.11 |
| 8 | 1.47 | 1.15 | 0.70 | 0.59 | 0.09 | 2 | 15 | 7 | 0.13 |
| 9 | 1.45 | 1.07 | 0.69 | 0.56 | 0.09 | 1 | 16 | 9 | 0.14 |
| 10 | 1.52 | 1.13 | 0.72 | 0.56 | 0.10 | 1 | 13 | 7 | 0.13 |
| 11 | 1.49 | 1.08 | 0.70 | 0.50 | 0.08 | 2 | 14 | 13 | 0.12 |
| 12 | 1.39 | 0.99 | 0.64 | 0.52 | 0.07 | 1 | 15 | 8 | 0.13 |
| 13 | 1.45 | 1.04 | 0.67 | 0.51 | 0.07 | 1 | 15 | 12 | 0.13 |
| 14 | 1.38 | 1.01 | 0.67 | 0.53 | 0.07 | 1 | 16 | 13 | 0.11 |
| 15 | 1.28 | 1.02 | 0.65 | 0.51 | 0.08 | 1 | 15 | 8 | 0.11 |
| 16 | 1.57 | 1.21 | 0.77 | 0.62 | 0.11 | 2.2 | 16 | 12 | 0.11 |
| 17 | 1.32 | 1.04 | 0.61 | 0.53 | 0.07 | 2 | 16 | 9 | 0.12 |
| 18 | 1.56 | 1.20 | 0.78 | 0.56 | 0.11 | 2 | 14 | 10 | 0.11 |
| 19 | 1.38 | 1.05 | 0.64 | 0.50 | 0.07 | 1 | 15 | 11 | 0.11 |

Appendix 2.11 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 1.62 | 1.18 | 0.84 | 0.56 | 0.13 | 2 | 15 | 12 | 0.11 |
| 21 | 1.46 | 1.06 | 0.67 | 0.53 | 0.08 | 2 | 16 | 14 | 0.13 |
| 22 | 1.55 | 1.19 | 0.80 | 0.52 | 0.11 | 2 | 15 | 10 | 0.12 |
| 23 | 1.47 | 1.12 | 0.66 | 0.56 | 0.09 | 2 | 16 | 10 | 0.13 |
| 24 | 1.54 | 1.20 | 0.76 | 0.61 | 0.11 | 2 | 15 | 11 | 0.13 |
| 25 | 1.76 | 1.31 | 0.82 | 0.64 | 0.14 | 2 | 15 | 12 | 0.11 |
| 26 | 1.41 | 1.05 | 0.69 | 0.52 | 0.08 | 1 | 16 | 13 | 0.11 |
| 27 | 1.64 | 1.17 | 0.78 | 0.59 | 0.12 | 2 | 13 | 8 | 0.11 |
| 28 | 1.66 | 1.20 | 0.86 | 0.63 | 0.13 | 1 | 14 | 12 | 0.12 |
| 29 | 1.39 | 1.05 | 0.67 | 0.54 | 0.07 | 2 | 15 | 8 | 0.11 |
| 30 | 1.46 | 1.09 | 0.71 | 0.55 | 0.09 | 2 | 15 | 12 | 0.12 |
| 31 | 1.67 | 1.23 | 0.78 | 0.58 | 0.11 | 2 | 16 | 10 | 0.13 |
| 32 | 1.57 | 1.14 | 0.75 | 0.57 | 0.10 | 2 | 15 | 10 | 0.13 |
| 33 | 1.53 | 1.15 | 0.74 | 0.56 | 0.09 | 2 | 16 | 10 | 0.11 |
| 34 | 1.46 | 1.10 | 0.72 | 0.53 | 0.08 | 2 | 16 | 12 | 0.13 |
| 35 | 1.58 | 1.17 | 0.75 | 0.54 | 0.10 | 2 | 13 | 10 | 0.12 |
| 36 | 1.32 | 0.99 | 0.69 | 0.49 | 0.07 | 1 | 14 | 9 | 0.11 |
| 37 | 1.48 | 1.06 | 0.72 | 0.53 | 0.09 | 2 | 15 | 10 | 0.11 |
| 38 | 1.64 | 1.20 | 0.81 | 0.58 | 0.11 | 1.4 | 15 | 11 | 0.11 |

Appendix 2.11 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 1.67 | 1.20 | 0.79 | 0.59 | 0.13 | 1.9 | 16 | 12 | 0.12 |
| 40 | 1.35 | 0.98 | 0.63 | 0.53 | 0.07 | 0.8 | 15 | 10 | 0.12 |
| 41 | 1.34 | 1.02 | 0.67 | 0.55 | 0.07 | 1.5 | 16 | 12 | 0.11 |
| 42 | 1.49 | 1.15 | 0.76 | 0.58 | 0.11 | 2.1 | 16 | 14 | 0.13 |
| 43 | 1.17 | 0.95 | 0.60 | 0.49 | 0.06 | 0.7 | 14 | 13 | 0.12 |
| 44 | 1.47 | 1.05 | 0.69 | 0.56 | 0.09 | 1.1 | 16 | 12 | 0.13 |
| 45 | 1.31 | 0.90 | 0.61 | 0.52 | 0.07 | 1.0 | 13 | 10 | 0.11 |
| 46 | 1.39 | 1.06 | 0.68 | 0.55 | 0.08 | 1.4 | 14 | 11 | 0.11 |
| 47 | 1.40 | 1.00 | 0.66 | 0.52 | 0.08 | 1.4 | 15 | 13 | 0.12 |
| 48 | 1.39 | 1.02 | 0.67 | 0.52 | 0.08 | 1.5 | 15 | 9 | 0.12 |
| 49 | 1.44 | 1.09 | 0.66 | 0.52 | 0.08 | 1.5 | 16 | 10 | 0.13 |
| 50 | 1.46 | 1.11 | 0.69 | 0.52 | 0.09 | 1.5 | 14 | 8 | 0.11 |

Appendix 2.12 Morphological data of juvenile spotted scat collected from mangrove forests in Pak Phanang Estuary, Nakhon Si Thammarat Province

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.24 | 1.76 | 1.11 | 0.80 | 0.37 | 1.5 | 16 | 16 | 0.17 |
| 2 | 2.20 | 1.78 | 1.07 | 0.80 | 0.31 | 4 | 16 | 13 | 0.18 |
| 3 | 2.22 | 1.77 | 1.13 | 0.81 | 0.34 | 4 | 15 | 17 | 0.16 |
| 4 | 2.09 | 1.66 | 0.99 | 0.71 | 0.25 | 2 | 15 | 18 | 0.17 |
| 5 | 2.36 | 1.83 | 1.14 | 0.81 | 0.38 | 4.5 | 16 | 13 | 0.18 |
| 6 | 2.14 | 1.70 | 1.12 | 0.71 | 0.28 | 2.5 | 18 | 17 | 0.15 |
| 7 | 2.05 | 1.58 | 0.97 | 0.68 | 0.24 | 1 | 17 | 16 | 0.17 |
| 8 | 2.87 | 2.16 | 1.43 | 0.96 | 0.71 | 4.2 | 15 | 14 | 0.18 |
| 9 | 2.52 | 1.90 | 1.30 | 0.85 | 0.46 | 2.2 | 17 | 13 | 0.18 |
| 10 | 2.30 | 1.73 | 1.13 | 0.77 | 0.47 | 4 | 17 | 12 | 0.15 |
| 11 | 2.12 | 1.61 | 1.06 | 0.73 | 0.30 | 4 | 15 | 16 | 0.15 |
| 12 | 2.51 | 1.95 | 1.26 | 0.82 | 0.42 | 5 | 18 | 18 | 0.21 |
| 13 | 3.09 | 2.34 | 1.54 | 1.01 | 0.79 | 6.1 | 16 | 18 | 0.20 |
| 14 | 2.56 | 2.02 | 1.27 | 0.89 | 0.35 | 5 | 16 | 14 | 0.17 |
| 15 | 2.45 | 1.85 | 1.28 | 0.91 | 0.47 | 5 | 17 | 14 | 0.18 |
| 16 | 2.21 | 1.74 | 1.12 | 0.79 | 0.33 | 5 | 17 | 19 | 0.18 |
| 17 | 4.40 | 3.51 | 2.27 | 1.40 | 2.84 | 9.9 | 17 | 16 | 0.18 |
| 18 | 4.67 | 3.64 | 2.32 | 1.46 | 3.26 | 11.5 | 17 | 16 | 0.18 |
| 19 | 5.63 | 4.29 | 2.90 | 1.79 | 5.61 | 11.3 | 16 | 14 | 0.20 |

Appendix 2.12 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 5.23 | 4.03 | 2.45 | 1.54 | 3.47 | 6 | 19 | 13 | 0.21 |
| 21 | 4.75 | 3.56 | 2.23 | 1.46 | 2.85 | 6 | 17 | 13 | 0.20 |
| 22 | 4.93 | 3.84 | 2.37 | 1.57 | 3.37 | 9 | 17 | 16 | 0.20 |
| 23 | 5.23 | 3.96 | 2.63 | 1.65 | 4.00 | 9.7 | 17 | 16 | 0.20 |
| 24 | 5.44 | 4.12 | 2.66 | 1.77 | 4.53 | 11.2 | 17 | 14 | 0.20 |
| 25 | 7.23 | 5.63 | 3.79 | 2.22 | 11.78 | 18 | 18 | 11 | 0.22 |
| 26 | 5.75 | 4.35 | 2.94 | 1.75 | 5.02 | 16 | 18 | 16 | 0.20 |
| 27 | 6.00 | 4.56 | 3.13 | 1.88 | 5.83 | 11.5 | 17 | 15 | 0.17 |
| 28 | 6.51 | 5.09 | 3.16 | 2.08 | 7.51 | 14 | 16 | 14 | 0.20 |
| 29 | 5.79 | 4.55 | 3.13 | 1.93 | 5.99 | 19.5 | 16 | 16 | 0.20 |
| 30 | 5.42 | 4.28 | 2.87 | 1.80 | 5.23 | 14 | 19 | 17 | 0.20 |
| 31 | 5.94 | 4.53 | 3.02 | 1.90 | 5.74 | 14.5 | 17 | 16 | 0.20 |
| 32 | 6.04 | 4.66 | 3.03 | 1.88 | 5.80 | 16.2 | 16 | 17 | 0.20 |
| 33 | 6.59 | 5.25 | 3.32 | 1.97 | 7.84 | 18.8 | 17 | 16 | 0.20 |
| 34 | 7.44 | 5.72 | 3.88 | 2.26 | 12.08 | 16 | 20 | 15 | 0.32 |
| 35 | 6.10 | 4.78 | 2.99 | 1.82 | 5.88 | 15.5 | 18 | 20 | 0.21 |
| 36 | 5.38 | 4.27 | 2.85 | 1.77 | 4.77 | 13.5 | 16 | 18 | 0.20 |
| 37 | 5.12 | 4.06 | 2.67 | 1.67 | 4.58 | 10 | 17 | 17 | 0.19 |
| 38 | 5.80 | 4.68 | 3.02 | 1.81 | 6.43 | 11.5 | 17 | 17 | 0.19 |

Appendix 2.12 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 7.20 | 5.44 | 3.53 | 2.11 | 10.09 | 12 | 18 | 22 | 0.29 |
| 40 | 5.71 | 4.36 | 2.78 | 1.69 | 4.77 | 11 | 18 | 16 | 0.18 |
| 41 | 5.78 | 4.49 | 3.16 | 1.80 | 5.49 | 13.5 | 18 | 16 | 0.19 |
| 42 | 4.72 | 3.72 | 2.59 | 1.55 | 3.77 | 10 | 17 | 16 | 0.17 |
| 43 | 4.32 | 3.33 | 2.27 | 1.44 | 2.65 | 11.5 | 17 | 16 | 0.17 |
| 44 | 3.87 | 2.98 | 2.09 | 1.31 | 1.80 | 8 | 18 | 16 | 0.15 |
| 45 | 5.47 | 4.21 | 2.78 | 1.71 | 4.32 | 12.2 | 17 | 14 | 0.18 |
| 46 | 5.51 | 4.25 | 2.72 | 1.67 | 4.34 | 15.3 | 17 | 15 | 0.17 |
| 47 | 3.96 | 3.02 | 2.12 | 1.34 | 1.92 | 8.5 | 18 | 17 | 0.15 |
| 48 | 3.44 | 2.64 | 1.83 | 1.15 | 1.33 | 8 | 17 | 17 | 0.18 |
| 49 | 3.03 | 2.34 | 1.59 | 1.12 | 1.07 | 5 | 16 | 17 | 0.17 |
| 50 | 4.26 | 3.26 | 2.19 | 1.37 | 2.25 | 8.8 | 18 | 14 | 0.19 |

Appendix 2.13 Morphological data of adult spotted scat collected from mangrove forests in Pak Phanang Estuary, Nakhon Si Thammarat Province

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 11.9 | 9.8 | 5.66 | 3.38 | 55.76 | 29.2 | 16 | 17 | 0.7 |
| 2 | 10.9 | 8.8 | 4.98 | 2.84 | 37.79 | 32 | 17 | 17 | 0.6 |
| 3 | 10.2 | 8.6 | 5.39 | 2.83 | 34.37 | 27 | 13 | 13 | 0.6 |
| 4 | 12.5 | 10.1 | 6.54 | 3.38 | 59.59 | 30 | 13 | 16 | 0.6 |
| 5 | 8.5 | 7 | 4.28 | 2.37 | 16.79 | 18.5 | 16 | 10 | 0.5 |
| 6 | 13.2 | 11 | 6.57 | 3.62 | 63.10 | 36 | 17 | 16 | 0.8 |
| 7 | 8.9 | 7.2 | 4.82 | 2.78 | 21.31 | 30 | 15 | 14 | 0.5 |
| 8 | 10.1 | 8 | 4.79 | 2.73 | 24.06 | 18.5 | 17 | 17 | 0.6 |
| 9 | 9.8 | 8 | 5.01 | 2.80 | 25.70 | 26 | 17 | 14 | 0.6 |
| 10 | 8.8 | 7.2 | 4.28 | 2.56 | 18.31 | 29 | 14 | 13 | 0.4 |
| 11 | 9.7 | 8 | 5.06 | 2.84 | 25.99 | 32 | 16 | 15 | 0.6 |
| 12 | 10.3 | 8.2 | 5.08 | 2.83 | 30.69 | 21.8 | 16 | 16 | 0.6 |
| 13 | 12.2 | 9.5 | 6.26 | 3.43 | 57.10 | 32.5 | 19 | 15 | 0.7 |
| 14 | 12.2 | 9.7 | 5.32 | 3.23 | 38.65 | 26 | 15 | 16 | 0.6 |
| 15 | 8.7 | 7 | 3.99 | 2.62 | 18.27 | 18 | 18 | 16 | 0.5 |
| 16 | 11 | 8.5 | 5.47 | 3.17 | 40.01 | 30 | 16 | 17 | 0.6 |
| 17 | 9.0 | 7.2 | 4.19 | 2.57 | 19.74 | 24 | 18 | 14 | 0.5 |
| 18 | 9.1 | 7.2 | 4.50 | 2.66 | 21.44 | 25 | 18 | 15 | 0.5 |
| 19 | 11.3 | 8.7 | 5.59 | 3.17 | 38.31 | 32 | 17 | 14 | 0.6 |

Appendix 2.13 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 9.4 | 7.3 | 4.44 | 2.87 | 22.76 | 28.4 | 18 | 17 | 0.6 |
| 21 | 11.9 | 9.2 | 5.81 | 3.25 | 47.04 | 30.5 | 18 | 18 | 0.7 |
| 22 | 11.5 | 9 | 5.18 | 3.22 | 37.27 | 30.5 | 17 | 13 | 0.6 |
| 23 | 9.6 | 7.5 | 4.57 | 2.81 | 24.55 | 21.5 | 17 | 18 | 0.6 |
| 24 | 11.4 | 8.8 | 4.75 | 3.09 | 38.64 | 28.5 | 18 | 14 | 0.7 |
| 25 | 11.0 | 8.6 | 5.16 | 3.03 | 40.89 | 24 | 17 | 17 | 0.6 |
| 26 | 10.9 | 8.4 | 5.38 | 3.03 | 37.19 | 32.3 | 17 | 17 | 0.6 |
| 27 | 8.6 | 6.5 | 4.04 | 2.62 | 18.55 | 23.5 | 20 | 16 | 0.4 |
| 28 | 8.5 | 6.5 | 4.14 | 2.52 | 16.90 | 22.5 | 18 | 14 | 0.5 |
| 29 | 11.2 | 8.9 | 5.21 | 3.04 | 39.15 | 24 | 17 | 18 | 0.7 |
| 30 | 9.2 | 7.2 | 4.69 | 2.68 | 24.39 | 20.5 | 15 | 15 | 0.6 |
| 31 | 9.0 | 7 | 4.62 | 2.61 | 21.23 | 17.2 | 16 | 16 | 0.6 |
| 32 | 9.5 | 7.5 | 5.08 | 2.80 | 28.77 | 28 | 17 | 13 | 0.6 |
| 33 | 10 | 8 | 4.89 | 2.87 | 29.43 | 21.7 | 17 | 16 | 0.6 |
| 34 | 9.1 | 7 | 4.86 | 2.62 | 23.08 | 22 | 18 | 17 | 0.5 |
| 35 | 10.0 | 7.7 | 4.75 | 2.87 | 27.87 | 29 | 17 | 19 | 0.6 |
| 36 | 17.7 | 14 | 8.13 | 4.59 | 130.51 | 36 | 20 | 20 | 0.8 |
| 37 | 16.0 | 13 | 7.67 | 4.19 | 119.80 | 33 | 17 | 18 | 0.6 |
| 38 | 15.5 | 12.3 | 7.34 | 4.02 | 111.75 | 37 | 17 | 16 | 0.7 |

Appendix 2.13 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 16.6 | 13.5 | 7.58 | 4.27 | 129.59 | 33 | 17 | 18 | 0.8 |
| 40 | 12.1 | 9.4 | 6.29 | 3.24 | 56.97 | 32 | 16 | 20 | 0.7 |
| 41 | 12.7 | 10.1 | 6.65 | 3.33 | 70.69 | 39 | 15 | 17 | 0.7 |
| 42 | 10.7 | 8.5 | 5.52 | 3.02 | 42.85 | 35 | 14 | 17 | 0.6 |
| 43 | 11.7 | 9.4 | 5.93 | 3.16 | 48.27 | 30 | 17 | 18 | 0.6 |
| 44 | 10.8 | 8.7 | 5.80 | 2.88 | 48.01 | 29.5 | 16 | 16 | 0.6 |
| 45 | 20.0 | 16.0 | 3.36 | 4.00 | 82.05 | 37 | 20 | 19 | 0.6 |
| 46 | 9.9 | 7.9 | 5.31 | 2.87 | 37.00 | 31.5 | 16 | 18 | 0.5 |
| 47 | 11.5 | 9.3 | 5.82 | 3.26 | 52.73 | 30 | 17 | 15 | 0.7 |
| 48 | 10.9 | 8.5 | 5.75 | 3.02 | 44.65 | 31 | 16 | 15 | 0.6 |
| 49 | 13.6 | 10.7 | 6.74 | 3.68 | 90.59 | 37 | 20 | 18 | 0.8 |
| 50 | 10.3 | 8.4 | 5.32 | 2.99 | 36.98 | 24 | 19 | 17 | 0.6 |

# APPENDIX III

## HISTOLOGICAL ADAPTATIONS IN DIGESTIVE SYSTEM AND FEEDING EFFICIENCY IN SPOTTED SCAT

Appendix 3.1 Histological Staining Protocol

1. Mayer's Hematoxylin and Eosin

Procedure

1. Deparaffinize and hydrate to water.
2. Mayer's hematoxylin for 15 minutes.
3. Wash in running tap water for 20 minutes.
4. Counterstain with eosin from 15 seconds to 2 minutes depending on the age of the eosin, and the depth of the counterstain desired. For even staining results dip slides several times before allowing them to set in the eosin for the desired time.
5. Dehydrate in 95% and absolute alcohols, two changes of 2 minutes each or until excess eosin is removed.
6. Clear in xylene, two changes of 2 minutes each.
7. Mount in Permount.

Results: Nuclei – blue with some metachromasia

Cytoplasm – various shades of pink –identifying different tissue components.

2. Alcian Blue for mucosustances pH 3.0

Procedure

1. Deparaffinize and hydrate to distilled water.
2. Mordant in 3% acetic acid solution for 3 minutes.
3. Alcian Blue solution for 30 minutes.
4. Wash in running water for 10 minutes.
5. Rinse in distilled water.
6. Counterstain in Kernechtrot solution for 5 minutes.
7. Wash in running water for 1 minute.
8. Dehyderate in 95% alcohol, absolute alcohol and clear in xylene, two changes each.
9. Mount with Permount.

Results: Strongly acidic sulfated mucosubstances - blue

Nuclei - pink to red

Cytoplasm - pale pink

3. Periodic Acid Schiff (PAS)

Procedure

1. Deparaffinize and hydrate to distilled water.
2. Place slides into 0.5% periodic acid solution for 5 minutes.
3. Rinse in distilled water.
4. Place in Schiff reagent for 15 minutes
5. Wash in lukewarm tap water for 5 minutes.
6. Counterstain in Mayer's hematoxylin for 1 minute.
7. Wash in tap water for 5 minutes.
8. Dehydrate and coverslip using a synthetic mounting medium.

Results: Glycogen, mucin and some basement membranes - red/purple

Background – blue

Appendix 3.2 ANOVA test of digestive system between three sizes of spotted scat

| **Alimentary system** | | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|---|
| Upper teeth length | Between Groups | 0.283 | 2 | 0.141 | 25.930 | 0.000* |
| | Within Groups | 0.065 | 12 | 0.005 | | |
| | Total | 0.348 | 14 | | | |
| Upper teeth width | Between Groups | 0.452 | 2 | 0.226 | 21.548 | 0.000* |
| | Within Groups | 0.126 | 12 | 0.010 | | |
| | Total | 0.578 | 14 | | | |
| Lower teeth length | Between Groups | 0.578 | 2 | 0.289 | 64.033 | 0.000* |
| | Within Groups | 0.054 | 12 | 0.005 | | |
| | Total | 0.633 | 14 | | | |
| Lower teeth width | Between Groups | 0.479 | 2 | 0.240 | 45.762 | 0.000* |
| | Within Groups | 0.063 | 12 | 0.005 | | |
| | Total | 0.542 | 14 | | | |
| Esophagus mucosa layer | Between Groups | 0.282 | 2 | 0.141 | 9.476 | 0.003* |
| | Within Groups | 0.179 | 12 | 0.015 | | |
| | Total | 0.461 | 14 | | | |
| Esophagus muscular layer | Between Groups | 2.290 | 2 | 1.145 | 165.003 | 0.000* |
| | Within Groups | 0.083 | 12 | 0.007 | | |
| | Total | 2.373 | 14 | | | |
| Cardiac mucosa layer | Between Groups | 0.318 | 2 | 0.159 | 100.601 | 0.000* |
| | Within Groups | 0.019 | 12 | 0.002 | | |
| | Total | 0.337 | 14 | | | |
| Cardiac muscular layer | Between Groups | 1.351 | 2 | 0.675 | 53.905 | 0.000* |
| | Within Groups | 0.150 | 12 | 0.013 | | |
| | Total | 1.501 | 14 | | | |
| Fundic mucosa layer | Between Groups | 0.066 | 2 | 0.033 | 8.460 | 0.005* |
| | Within Groups | 0.047 | 12 | 0.004 | | |
| | Total | 0.112 | 14 | | | |

Remark: * The mean difference is significant at the 0.05 level

Appendix 3.2 (Continued)

| Alimentary system | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Fundic muscular layer | Between Groups | 0.253 | 2 | 0.127 | 10.024 | 0.003* |
| | Within Groups | 0.152 | 12 | 0.013 | | |
| | Total | 0.405 | 14 | | | |
| Pyloric mucosa layer | Between Groups | 0.046 | 2 | 0.023 | 5.110 | 0.025* |
| | Within Groups | 0.054 | 12 | 0.005 | | |
| | Total | 0.100 | 14 | | | |
| Pyloric muscular layer | Between Groups | 0.887 | 2 | 0.443 | 50.243 | 0.000* |
| | Within Groups | 0.106 | 12 | 0.009 | | |
| | Total | 0.993 | 14 | | | |
| Duodenum mucosa layer | Between Groups | 0.418 | 2 | 0.209 | 30.195 | 0.000* |
| | Within Groups | 0.083 | 12 | 0.007 | | |
| | Total | 0.501 | 14 | | | |
| Duodenum muscular layer | Between Groups | 2.650 | 2 | 1.325 | 76.711 | 0.000* |
| | Within Groups | 0.207 | 12 | 0.017 | | |
| | Total | 2.857 | 14 | | | |
| Jejunum mucosa layer | Between Groups | 2.239 | 2 | 1.119 | 105.967 | 0.000* |
| | Within Groups | 0.127 | 12 | 0.011 | | |
| | Total | 2.365 | 14 | | | |
| Jejunum muscular layer | Between Groups | 4.942 | 2 | 2.471 | 413.024 | 0.000* |
| | Within Groups | 0.072 | 12 | 0.006 | | |
| | Total | 5.014 | 14 | | | |
| Ileum mucosa layer | Between Groups | 0.619 | 2 | 0.309 | 21.321 | 0.000* |
| | Within Groups | 0.174 | 12 | 0.015 | | |
| | Total | 0.793 | 14 | | | |
| Ileum muscular layer | Between Groups | 0.717 | 2 | 0.359 | 18.588 | 0.000* |
| | Within Groups | 0.232 | 12 | 0.019 | | |
| | Total | 0.949 | 14 | | | |

Remark: * The mean difference is significant at the 0.05 level

# Post Hoc Tests

**Multiple Comparisons**

Tukey HSD

| Dependent Variable | (I) size | (J) size | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| UpperteethLength | Larvae | Juveniles | -.29331* | .04668 | .00011 | -.41785 | -.16876 |
| | | Adults | -.28892* | .04668 | .00013 | -.41346 | -.16438 |
| | Juveniles | Larvae | .29331* | .04668 | .00011 | .16876 | .41785 |
| | | Adults | .00439 | .04668 | .99515 | -.12016 | .12893 |
| | Adults | Larvae | .28892* | .04668 | .00013 | .16438 | .41346 |
| | | Juveniles | -.00439 | .04668 | .99515 | -.12893 | .12016 |
| UpperteethWidth | Larvae | Juveniles | -.30760* | .06481 | .00127 | -.48049 | -.13471 |
| | | Adults | -.40833* | .06481 | .00011 | -.58122 | -.23543 |
| | Juveniles | Larvae | .30760* | .06481 | .00127 | .13471 | .48049 |
| | | Adults | -.10073 | .06481 | .30189 | -.27362 | .07217 |
| | Adults | Larvae | .40833* | .06481 | .00011 | .23543 | .58122 |
| | | Juveniles | .10073 | .06481 | .30189 | -.07217 | .27362 |
| LowerteethLength | Larvae | Juveniles | -.37900* | .04251 | .00000 | -.49240 | -.26560 |
| | | Adults | -.44604* | .04251 | .00000 | -.55944 | -.33264 |
| | Juveniles | Larvae | .37900* | .04251 | .00000 | .26560 | .49240 |
| | | Adults | -.06704 | .04251 | .29242 | -.18044 | .04637 |
| | Adults | Larvae | .44604* | .04251 | .00000 | .33264 | .55944 |
| | | Juveniles | .06704 | .04251 | .29242 | -.04637 | .18044 |
| LowerteethWidth | Larvae | Juveniles | -.34810* | .04577 | .00002 | -.47021 | -.22599 |
| | | Adults | -.40410* | .04577 | .00000 | -.52621 | -.28199 |
| | Juveniles | Larvae | .34810* | .04577 | .00002 | .22599 | .47021 |
| | | Adults | -.05600 | .04577 | .46253 | -.17811 | .06611 |
| | Adults | Larvae | .40410* | .04577 | .00000 | .28199 | .52621 |
| | | Juveniles | .05600 | .04577 | .46253 | -.06611 | .17811 |
| EsophagusMucosalayer | Larvae | Juveniles | -.32994* | .07715 | .00285 | -.53578 | -.12410 |
| | | Adults | -.21946* | .07715 | .03659 | -.42529 | -.01362 |
| | Juveniles | Larvae | .32994* | .07715 | .00285 | .12410 | .53578 |
| | | Adults | .11048 | .07715 | .35635 | -.09535 | .31632 |
| | Adults | Larvae | .21946* | .07715 | .03659 | .01362 | .42529 |
| | | Juveniles | -.11048 | .07715 | .35635 | -.31632 | .09535 |
| EsophagusMuscularlayer | Larvae | Juveniles | -.64594* | .05269 | .00000 | -.78650 | -.50538 |
| | | Adults | -.93463* | .05269 | .00000 | -1.07519 | -.79407 |
| | Juveniles | Larvae | .64594* | .05269 | .00000 | .50538 | .78650 |
| | | Adults | -.28869* | .05269 | .00038 | -.42925 | -.14813 |
| | Adults | Larvae | .93463* | .05269 | .00000 | .79407 | 1.07519 |
| | | Juveniles | .28869* | .05269 | .00038 | .14813 | .42925 |

*. The mean difference is significant at the .05 level.

**Multiple Comparisons**

Tukey HSD

| Dependent Variable | (I) size | (J) size | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| CardiacMucosalayer | Larvae | Juveniles | -.25892* | .02515 | .00000 | -.32602 | -.19181 |
| | | Adults | -.34203* | .02515 | .00000 | -.40914 | -.27493 |
| | Juveniles | Larvae | .25892* | .02515 | .00000 | .19181 | .32602 |
| | | Adults | -.08312* | .02515 | .01605 | -.15022 | -.01601 |
| | Adults | Larvae | .34203* | .02515 | .00000 | .27493 | .40914 |
| | | Juveniles | .08312* | .02515 | .01605 | .01601 | .15022 |
| CardiacMuscularlayer | Larvae | Juveniles | -.59628* | .07079 | .00001 | -.78515 | -.40742 |
| | | Adults | -.67037* | .07079 | .00000 | -.85924 | -.48151 |
| | Juveniles | Larvae | .59628* | .07079 | .00001 | .40742 | .78515 |
| | | Adults | -.07409 | .07079 | .56324 | -.26295 | .11478 |
| | Adults | Larvae | .67037* | .07079 | .00000 | .48151 | .85924 |
| | | Juveniles | .07409 | .07079 | .56324 | -.11478 | .26295 |
| FundicMucosalayer | Larvae | Juveniles | .00854 | .03939 | .97450 | -.09654 | .11361 |
| | | Adults | -.13584* | .03939 | .01238 | -.24092 | -.03076 |
| | Juveniles | Larvae | -.00854 | .03939 | .97450 | -.11361 | .09654 |
| | | Adults | -.14438* | .03939 | .00840 | -.24946 | -.03930 |
| | Adults | Larvae | .13584* | .03939 | .01238 | .03076 | .24092 |
| | | Juveniles | .14438* | .03939 | .00840 | .03930 | .24946 |
| FundicMuscularlayer | Larvae | Juveniles | .01191 | .07111 | .98469 | -.17780 | .20161 |
| | | Adults | -.26959* | .07111 | .00671 | -.45930 | -.07988 |
| | Juveniles | Larvae | -.01191 | .07111 | .98469 | -.20161 | .17780 |
| | | Adults | -.28149* | .07111 | .00499 | -.47120 | -.09178 |
| | Adults | Larvae | .26959* | .07111 | .00671 | .07988 | .45930 |
| | | Juveniles | .28149* | .07111 | .00499 | .09178 | .47120 |
| PyloricMucosalayer | Larvae | Juveniles | -.08025 | .04251 | .18440 | -.19366 | .03315 |
| | | Adults | -.13509* | .04251 | .02014 | -.24850 | -.02169 |
| | Juveniles | Larvae | .08025 | .04251 | .18440 | -.03315 | .19366 |
| | | Adults | -.05484 | .04251 | .42691 | -.16824 | .05856 |
| | Adults | Larvae | .13509* | .04251 | .02014 | .02169 | .24850 |
| | | Juveniles | .05484 | .04251 | .42691 | -.05856 | .16824 |
| PyloricMuscularlayer | Larvae | Juveniles | -.33343* | .05941 | .00031 | -.49194 | -.17492 |
| | | Adults | -.59410* | .05941 | .00000 | -.75261 | -.43559 |
| | Juveniles | Larvae | .33343* | .05941 | .00031 | .17492 | .49194 |
| | | Adults | -.26067* | .05941 | .00235 | -.41918 | -.10216 |
| | Adults | Larvae | .59410* | .05941 | .00000 | .43559 | .75261 |
| | | Juveniles | .26067* | .05941 | .00235 | .10216 | .41918 |

*. The mean difference is significant at the .05 level.

**Multiple Comparisons**

Tukey HSD

| Dependent Variable | (I) size | (J) size | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| DuodenumMucosalayer | Larvae | Juveniles | -.01123 | .05264 | .97526 | -.15166 | .12920 |
| | | Adults | -.35973* | .05264 | .00005 | -.50016 | -.21930 |
| | Juveniles | Larvae | .01123 | .05264 | .97526 | -.12920 | .15166 |
| | | Adults | -.34850* | .05264 | .00007 | -.48893 | -.20807 |
| | Adults | Larvae | .35973* | .05264 | .00005 | .21930 | .50016 |
| | | Juveniles | .34850* | .05264 | .00007 | .20807 | .48893 |
| DuodenumMuscularlayer | Larvae | Juveniles | -.76282* | .08312 | .00000 | -.98458 | -.54105 |
| | | Adults | -.98028* | .08312 | .00000 | -1.20204 | -.75851 |
| | Juveniles | Larvae | .76282* | .08312 | .00000 | .54105 | .98458 |
| | | Adults | -.21746 | .08312 | .05475 | -.43922 | .00430 |
| | Adults | Larvae | .98028* | .08312 | .00000 | .75851 | 1.20204 |
| | | Juveniles | .21746 | .08312 | .05475 | -.00430 | .43922 |
| JejunumMucosalayer | Larvae | Juveniles | -.66756* | .06500 | .00000 | -.84097 | -.49415 |
| | | Adults | -.91458* | .06500 | .00000 | -1.08799 | -.74117 |
| | Juveniles | Larvae | .66756* | .06500 | .00000 | .49415 | .84097 |
| | | Adults | -.24703* | .06500 | .00660 | -.42044 | -.07362 |
| | Adults | Larvae | .91458* | .06500 | .00000 | .74117 | 1.08799 |
| | | Juveniles | .24703* | .06500 | .00660 | .07362 | .42044 |
| JejunumMuscularlayer | Larvae | Juveniles | -1.02066* | .04892 | .00000 | -1.15117 | -.89016 |
| | | Adults | -1.34772* | .04892 | .00000 | -1.47822 | -1.21721 |
| | Juveniles | Larvae | 1.02066* | .04892 | .00000 | .89016 | 1.15117 |
| | | Adults | -.32705* | .04892 | .00006 | -.45756 | -.19655 |
| | Adults | Larvae | 1.34772* | .04892 | .00000 | 1.21721 | 1.47822 |
| | | Juveniles | .32705* | .04892 | .00006 | .19655 | .45756 |
| IleumMucosalayer | Larvae | Juveniles | -.33007* | .07617 | .00259 | -.53328 | -.12685 |
| | | Adults | -.48729* | .07617 | .00009 | -.69050 | -.28407 |
| | Juveniles | Larvae | .33007* | .07617 | .00259 | .12685 | .53328 |
| | | Adults | -.15722 | .07617 | .13945 | -.36043 | .04599 |
| | Adults | Larvae | .48729* | .07617 | .00009 | .28407 | .69050 |
| | | Juveniles | .15722 | .07617 | .13945 | -.04599 | .36043 |
| IleumMuscularlayer | Larvae | Juveniles | -.44625* | .08785 | .00073 | -.68062 | -.21188 |
| | | Adults | -.47969* | .08785 | .00039 | -.71405 | -.24532 |
| | Juveniles | Larvae | .44625* | .08785 | .00073 | .21188 | .68062 |
| | | Adults | -.03343 | .08785 | .92376 | -.26780 | .20093 |
| | Adults | Larvae | .47969* | .08785 | .00039 | .24532 | .71405 |
| | | Juveniles | .03343 | .08785 | .92376 | -.20093 | .26780 |

*. The mean difference is significant at the .05 level.

Appendix 3.3 ANOVA test of proximate analysis from three stages of spotted scat

| **Proximate Analysis** | | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|---|
| %Dry matter | Between Groups | 0.049 | 2 | 0.025 | 9.395 | 0.020* |
| | Within Groups | 0.013 | 5 | 0.003 | | |
| | Total | 0.062 | 7 | | | |
| %Crude protein | Between Groups | 0.313 | 2 | 0.156 | 16.208 | 0.007* |
| | Within Groups | 0.048 | 5 | 0.010 | | |
| | Total | 0.361 | 7 | | | |
| %Ash | Between Groups | 0.016 | 2 | 0.008 | 3.844 | 0.097 |
| | Within Groups | 0.011 | 5 | 0.002 | | |
| | Total | 0.027 | 7 | | | |
| %Crude fiber | Between Groups | 1.620 | 2 | 0.810 | 10.069 | 0.018* |
| | Within Groups | 0.402 | 5 | 0.080 | | |
| | Total | 2.022 | 7 | | | |

Remark: * The mean difference is significant at the 0.05 level

## Post Hoc Tests

**Multiple Comparisons**

Tukey HSD

| Dependent Variable | (I) size | (J) size | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Drymatter | Larvae | Juveniles | .0111973 | .0467756 | .969 | -.141006 | .163401 |
| | | Adults | .1686761* | .0467756 | .035 | .016472 | .320880 |
| | Juveniles | Larvae | -.0111973 | .0467756 | .969 | -.163401 | .141006 |
| | | Adults | .1574788* | .0418374 | .029 | .021344 | .293614 |
| | Adults | Larvae | -.1686761* | .0467756 | .035 | -.320880 | -.016472 |
| | | Juveniles | -.1574788* | .0418374 | .029 | -.293614 | -.021344 |
| Crudeprotein | Larvae | Juveniles | -.4815909* | .0896607 | .007 | -.773339 | -.189843 |
| | | Adults | -.4243812* | .0896607 | .012 | -.716129 | -.132633 |
| | Juveniles | Larvae | .4815909* | .0896607 | .007 | .189843 | .773339 |
| | | Adults | .0572097 | .0801950 | .767 | -.203738 | .318157 |
| | Adults | Larvae | .4243812* | .0896607 | .012 | .132633 | .716129 |
| | | Juveniles | -.0572097 | .0801950 | .767 | -.318157 | .203738 |
| Ash | Larvae | Juveniles | -.0722357 | .0422490 | .290 | -.209710 | .065239 |
| | | Adults | -.1171147 | .0422490 | .085 | -.254589 | .020360 |
| | Juveniles | Larvae | .0722357 | .0422490 | .290 | -.065239 | .209710 |
| | | Adults | -.0448790 | .0377887 | .509 | -.167840 | .078082 |
| | Adults | Larvae | .1171147 | .0422490 | .085 | -.020360 | .254589 |
| | | Juveniles | .0448790 | .0377887 | .509 | -.078082 | .167840 |
| Crudefiber | Larvae | Juveniles | -1.0842550* | .2589363 | .020 | -1.926811 | -.241699 |
| | | Adults | -.9847960* | .2589363 | .028 | -1.827352 | -.142240 |
| | Juveniles | Larvae | 1.0842550* | .2589363 | .020 | .241699 | 1.926811 |
| | | Adults | .0994589 | .2315996 | .905 | -.654146 | .853064 |
| | Adults | Larvae | .9847960* | .2589363 | .028 | .142240 | 1.827352 |
| | | Juveniles | -.0994589 | .2315996 | .905 | -.853064 | .654146 |

*. The mean difference is significant at the .05 level.

# APPENDIX IV

## NICHE PARTITIONING IN SPOTTED SCAT, *Scatophagus argus* AND ADULT TADE MULLET, *Liza planiceps* COMMUNITIES

Appendix 4.1 ANOVA test of food components of tade mullet between months in high salinity

| **Prey items** | | **Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|---|
| Cynophyceae | Between Groups | 0.077 | 2 | 0.038 | 0.190 | 0.830 |
| | Within Groups | 1.820 | 9 | 0.202 | | |
| | Total | 1.896 | 11 | | | |
| Chlorophyceae | Between Groups | 0.785 | 1 | 0.785 | 1.287 | 0.460 |
| | Within Groups | 0.610 | 1 | 0.610 | | |
| | Total | 1.396 | 2 | | | |
| Bacillariophyceae | Between Groups | 0.019 | 2 | 0.010 | 0.387 | 0.690 |
| | Within Groups | 0.225 | 9 | 0.025 | | |
| | Total | 0.245 | 11 | | | |
| Dinophyceae | Between Groups | 0.027 | 2 | 0.013 | 0.028 | 0.972 |
| | Within Groups | 4.206 | 9 | 0.467 | | |
| | Total | 4.232 | 11 | | | |
| Protozoa | Between Groups | 1.343 | 2 | 0.672 | 1.014 | 0.401 |
| | Within Groups | 5.964 | 9 | 0.663 | | |
| | Total | 7.307 | 11 | | | |
| Zooplankton | Between Groups | 2.166 | 2 | 1.083 | 2.436 | 0.143 |
| | Within Groups | 4.001 | 9 | 0.445 | | |
| | Total | 6.167 | 11 | | | |
| Benthos | Between Groups | 0.100 | 2 | 0.050 | 0.125 | 0.884 |
| | Within Groups | 3.621 | 9 | 0.402 | | |
| | Total | 3.721 | 11 | | | |
| Detritus | Between Groups | 0.485 | 2 | 0.243 | 0.621 | 0.559 |
| | Within Groups | 3.514 | 9 | 0.390 | | |
| | Total | 3.999 | 11 | | | |

Appendix 4.2 Independent sample *t-test* of food components of tade mullet between high and low salinity

| Prey items | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig.(2-tailed) |
| Cyanophyceae | Equal variances assumed | 2.888 | 0.113 | -2.273 | 13 | 0.041* |
| | Equal variances not assumed | | | -3.607 | 8.334 | 0.006 |
| Chlorophyceae | Equal variances assumed | 0.046 | 0.840 | -2.311 | 4 | 0.082 |
| | Equal variances not assumed | | | -2.311 | 3.922 | 0.083 |
| Euglenophyceae | Equal variances assumed | 0.918 | 0.409 | -1.824 | 3 | 0.166 |
| | Equal variances not assumed | | | -2.163 | 2.873 | 0.123 |
| Bacillariophyceae | Equal variances assumed | 0.035 | 0.855 | 1.410 | 13 | 0.182 |
| | Equal variances not assumed | | | 1.538 | 3.460 | 0.210 |
| Dinophyceae | Equal variances assumed | 0.325 | 0.578 | -0.320 | 13 | 0.754 |
| | Equal variances not assumed | | | -0.321 | 3.100 | 0.769 |
| Protozoa | Equal variances assumed | 1.576 | 0.231 | 0.610 | 13 | 0.552 |
| | Equal variances not assumed | | | 1.010 | 9.598 | 0.337 |
| Zooplankton | Equal variances assumed | 2.167 | 0.165 | 0.364 | 13 | 0.722 |
| | Equal variances not assumed | | | 0.555 | 7.327 | 0.595 |
| Insects | Equal variances assumed | 0.546 | 0.473 | -0.051 | 13 | 0.960 |
| | Equal variances not assumed | | | -0.064 | 4.378 | 0.952 |
| Detritus | Equal variances assumed | 0.008 | 0.932 | 0.068 | 13 | 0.947 |
| | Equal variances not assumed | | | 0.062 | 2.788 | 0.955 |

Remark: * The mean difference is significant at the 0.05 level

Appendix 4.3 Independent sample *t-test* of food components of tade mullet between mangrove forests and estuarine waterways

| Prey items | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | |
|---|---|---|---|---|---|---|
| | | **F** | **Sig.** | **t** | **df** | **Sig.(2-tailed)** |
| Cyanophyta | Equal variances assumed | 1.153 | 0.302 | 1.647 | 13 | 0.123 |
| | Equal variances not assumed | | | 2.153 | 4.810 | 0.086 |
| Chlorophyceae | Equal variances assumed | 0.023 | 0.887 | 2.638 | 4 | 0.058 |
| | Equal variances not assumed | | | 2.521 | 1.866 | 0.137 |
| Bacillariophyceae | Equal variances assumed | 4.393 | 0.056 | -2.137 | 13 | 0.052 |
| | Equal variances not assumed | | | -4.259 | 12.247 | 0.001 |
| Dinophyceae | Equal variances assumed | 4.432 | 0.055 | 2.663 | 13 | 0.020* |
| | Equal variances not assumed | | | 4.156 | 7.884 | 0.003 |
| Protozoan | Equal variances assumed | 1.037 | 0.327 | 3.287 | 13 | 0.006* |
| | Equal variances not assumed | | | 4.781 | 6.336 | 0.003 |
| Zooplankton | Equal variances assumed | 1.724 | 0.212 | 4.023 | 13 | 0.001* |
| | Equal variances not assumed | | | 6.816 | 10.339 | 0.000 |
| Insects | Equal variances assumed | 0.346 | 0.566 | 2.814 | 13 | 0.015* |
| | Equal variances not assumed | | | 2.333 | 2.588 | 0.116 |
| Detritus | Equal variances assumed | 2.886 | 0.113 | 1.496 | 13 | 0.159 |
| | Equal variances not assumed | | | 2.522 | 10.173 | 0.030 |

Remark: * The mean difference is significant at the 0.05 level

Appendix 4.4 Morphological data of adult tade mullets collected from mangrove forests in Pak Phanang Estuary, Nakhon Si Thammarat Province

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.00 | 16.00 | 3.36 | 4.00 | 84.00 | 41.00 | 97 | 5 | 1.00 |
| 2 | 13.65 | 10.62 | 2.81 | 2.89 | 32.00 | 30.00 | 93 | 5 | 0.80 |
| 3 | 12.75 | 9.76 | 2.79 | 2.70 | 28.00 | 28.00 | 95 | 5 | 0.90 |
| 4 | 10.70 | 8.40 | 2.44 | 2.40 | 18.00 | 26.50 | 90 | 5 | 0.80 |
| 5 | 14.20 | 10.69 | 3.00 | 2.99 | 34.00 | 29.00 | 92 | 5 | 0.90 |
| 6 | 13.80 | 10.64 | 2.77 | 3.00 | 30.00 | 28.50 | 92 | 5 | 0.80 |
| 7 | 11.10 | 8.53 | 2.21 | 2.55 | 15.00 | 22.50 | 87 | 5 | 0.80 |
| 8 | 14.50 | 11.30 | 2.58 | 3.11 | 30.00 | 29.00 | 97 | 5 | 0.90 |
| 9 | 15.90 | 12.75 | 3.11 | 3.23 | 50.00 | 32.00 | 97 | 5 | 0.90 |
| 10 | 17.50 | 14.02 | 3.20 | 3.74 | 56.00 | 40.00 | 97 | 5 | 1.00 |
| 11 | 16.50 | 12.70 | 3.29 | 3.45 | 56.00 | 34.50 | 94 | 5 | 1.00 |
| 12 | 14.10 | 11.44 | 3.29 | 3.00 | 41.00 | 29.50 | 94 | 5 | 0.90 |
| 13 | 23.40 | 18.30 | 3.97 | 4.72 | 40.00 | 47.50 | 96 | 5 | 1.00 |
| 14 | 18.70 | 14.70 | 3.24 | 3.88 | 72.00 | 41.30 | 93 | 5 | 0.80 |
| 15 | 17.30 | 13.40 | 3.77 | 3.79 | 68.00 | 35.00 | 94 | 5 | 0.90 |
| 16 | 14.70 | 11.41 | 3.15 | 3.09 | 43.00 | 39.40 | 90 | 5 | 0.80 |
| 17 | 16.80 | 13.20 | 3.57 | 3.51 | 66.00 | 40.00 | 92 | 5 | 0.90 |
| 18 | 18.20 | 14.00 | 3.83 | 3.79 | 79.00 | 36.70 | 97 | 5 | 1.00 |
| 19 | 15.50 | 12.19 | 3.46 | 3.51 | 51.00 | 31.50 | 95 | 5 | 0.90 |

Appendix 4.4 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 11.60 | 8.95 | 2.52 | 2.53 | 20.00 | 24.00 | 97 | 5 | 0.80 |
| 21 | 22.50 | 15.80 | 4.80 | 4.25 | 142.00 | 50.00 | 96 | 5 | 0.80 |
| 22 | 18.85 | 15.50 | 3.61 | 4.15 | 86.00 | 49.50 | 94 | 5 | 1.00 |
| 23 | 20.00 | 15.30 | 3.65 | 4.16 | 86.00 | 43.00 | 96 | 5 | 0.90 |
| 24 | 18.00 | 14.50 | 3.61 | 3.93 | 79.00 | 45.50 | 95 | 5 | 1.00 |
| 25 | 16.85 | 13.19 | 3.47 | 3.55 | 57.00 | 46.00 | 95 | 5 | 0.90 |
| 26 | 21.10 | 16.10 | 3.40 | 4.14 | 100.00 | 50.00 | 94 | 5 | 0.80 |
| 27 | 19.45 | 15.02 | 3.31 | 3.75 | 75.00 | 40.00 | 97 | 5 | 1.00 |
| 28 | 10.00 | 8.23 | 4.80 | 2.90 | 36.00 | 21.00 | 68 | 5 | 0.90 |
| 29 | 23.00 | 20.50 | 4.65 | 5.62 | 222.00 | 92.50 | 92 | 5 | 0.80 |
| 30 | 25.70 | 22.20 | 5.33 | 5.78 | 256.00 | 90.00 | 97 | 5 | 0.90 |
| 31 | 14.70 | 11.86 | 2.78 | 3.22 | 38.00 | 32.20 | 93 | 5 | 1.00 |
| 32 | 14.80 | 11.29 | 3.07 | 3.29 | 38.00 | 29.80 | 90 | 5 | 0.90 |
| 33 | 14.70 | 11.08 | 3.44 | 3.21 | 43.00 | 31.50 | 92 | 5 | 0.90 |
| 34 | 15.00 | 11.63 | 2.69 | 3.21 | 34.00 | 32.00 | 95 | 5 | 0.80 |
| 35 | 11.60 | 9.10 | 2.45 | 2.68 | 19.00 | 25.00 | 90 | 5 | 0.90 |
| 36 | 13.00 | 9.96 | 2.70 | 2.95 | 28.00 | 28.50 | 93 | 5 | 0.80 |
| 37 | 12.70 | 9.72 | 2.20 | 2.84 | 22.00 | 25.40 | 90 | 5 | 0.90 |
| 38 | 12.60 | 9.69 | 2.39 | 2.72 | 22.00 | 26.50 | 90 | 5 | 0.80 |

Appendix 4.4 (Continued)

| No. | Total length (cm.) | Standard length (cm.) | Body depth (cm.) | Head length (cm.) | Wet weight (g.) | Intestine length (cm.) | Gill rakers | Number of Pyloric caeca | Width of mouth gape (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 10.20 | 7.83 | 2.02 | 2.24 | 14.00 | 22.50 | 87 | 5 | 0.90 |
| 40 | 21.00 | 16.80 | 4.11 | 4.04 | 115.00 | 43.50 | 97 | 5 | 0.90 |
| 41 | 17.30 | 13.50 | 3.47 | 3.57 | 63.00 | 37.00 | 92 | 5 | 0.90 |
| 42 | 19.40 | 14.80 | 3.43 | 3.90 | 74.00 | 41.00 | 97 | 5 | 1.00 |
| 43 | 18.00 | 13.94 | 3.20 | 3.36 | 59.00 | 36.00 | 97 | 5 | 1.00 |
| 44 | 16.40 | 12.68 | 3.68 | 3.40 | 58.00 | 37.00 | 95 | 5 | 0.90 |
| 45 | 18.70 | 15.30 | 3.80 | 3.84 | 86.00 | 43.00 | 93 | 5 | 0.80 |
| 46 | 17.30 | 13.30 | 3.56 | 3.82 | 74.00 | 50.00 | 93 | 5 | 1.00 |
| 47 | 18.60 | 14.70 | 3.92 | 3.84 | 88.00 | 40.30 | 90 | 5 | 1.00 |
| 48 | 26.00 | 20.30 | 5.40 | 5.24 | 233.00 | 52.00 | 97 | 5 | 1.00 |
| 49 | 19.00 | 15.27 | 3.32 | 4.03 | 78.00 | 49.00 | 96 | 5 | 0.90 |
| 50 | 18.00 | 13.94 | 3.20 | 3.36 | 59.00 | 37.00 | 97 | 5 | 0.90 |

# BIOGRAPHY

Miss Supichaya Wongchinawit was born on the 31 December, 1977. She received her bachelor's degree of Science in Department of Fisheries from Faculty of Agriculture, Khon Kaen University in 1999. She received her Master's degree of Marine Science from Department of Marine Science, Faculty of Fisheries, Kasetsart University in 2002. Her graduate study for Doctoral's degree of Marine Science in Department of Marine Science, Faculty of Science, Chulalongkorn University was financially supported by TRF/BIOTECH Special Program for Biodiversity Research and Training grant T_349007 and by Research grant of Graduate School, Chulalongkorn University.