EFFECTS OF SALINITY ON THE SURVIVAL, GROWTH AND DEVELOPMENT OF SENSORY ORGANS, AND GILL CHLORIDE CELLS OF MARBLE GOBY, *Oxyeleotris marmoratus* LARVAE

SOW SOK HUI

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

BORNEO MARINE RESEARCH INSTITUTE
UNIVERSITI MALAYSIA SABAH

2007

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS*

JUDUL : Effects of Salinity on the Survival, Growth, Development of Sensory Organs, and Gill Chloride Cells of Marble Goby, *Oxyeleotris marmoratus* Larvae

IJAZAH : Sarjana Sains (Akuakultur)

SESI PENGAJIAN : 2003-2007

Saya, SOW SOK HUI, mengaku membenarkan tesis Sarjana Sains ini disimpan dia Perpustakaan Universiti Malysia Sabah dengan syarat- syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. TIDAK TERHAD

Disahkan oleh:

(Penulis: SOW SOK HUI)

(TANDATANGAN PUSTAKAWAN)

Alamat Tetap:
565-1, Jln Johor,
82000 Pontian,
Johor Darul Takzim
Email: cindysow@hotmail.com

(Penyelia: Prof. Dr. Shigeharu Senoo)

Tarikh:

Tarikh:

CATATAN: * Tesis dimaksudkan sebagai tesis ijazah Sarjana Sains secara penyelidikan, atau disertasi bagi pengajian secara penyelidikan

DECLARATION

The materials in this thesis are original except for quotations, excerpts, summaries and references, which have been duly acknowledged.

Sok Hui

SOW SOK HUI
PS 03-004-007
14 March 2007

ACKNOWLEDGEMENTS

I would like to express my sincere grateful acknowledgement to my supervisors, Prof. Dr. Shigeharu Senoo and Dr. Yukinori Mukai, Borneo Marine Research Institute, for their invaluable suggestions, guidance and encouragement throughout the study period.

I wish to express heartily my indebtedness to Prof. Dr. Saleem Mustafa, Director of Borneo Marine Research Institute, Prof. Dr. Ridzwan Abdul Rahman, Director of Centre for Research Management and Conference (the former Director of Borneo Marine Research Institute), Prof. Datin Dr. Maryati Mohamed, Acting Dean of Centre for Postgraduate Studies and Prof. Datuk Dr. Mohd. Noh Dalimin, Vice-chancellor, Universiti Malaysia Sabah, for their encouragement and assistance.

My sincere appreciation also to Mr. Motinius Guntalib, Mr. Norazmi Osman, Mr. Henry Lipan and all the staff of Fish Hatchery, Borneo Marine Research Institute for their assistance, to my friends, colleagues and well-wishers for their valuable inputs directly or indirectly for the successful completion of the thesis.

I also extend my thanks to Prof. Dr. Masaru Tanaka, Kyoto University for his meaningful comments and advice. I extend thanks to Miss Yuuho Takeda and Hirona Makino for methodological assistance in the immunology experiment.

Last but not the least, a special note of thanks to my parents for their patience, encouragement, support and understanding in my absence.

ABSTRAK

PERBEZAAN PARAS SALINITI TERHADAP KEMANDIRAN, TUMBESARAN, PERKEMBANGAN ORGAN DERIA DAN SEL KLORIDA INSANG PADA LARVA IKAN KETUTU, *Oxyeleotris marmoratus*

Ikan ketutu, *Oxyeleotris marmoratus* merupakan ikan air tawar yang paling penting dalam industri akuakultur kerana mempunyai permintaan dan harga pasaran yang tinggi. Masalah utama dalam pengkulturan *O. marmoratus* adalah kekurangan sumber benih yang disebabkan oleh penangkapan berlebihan. Antara masalah lain ialah kadar kematian yang tinggi pada peringkat awal larva dalam keadaan pengkulturan tiruan. Eksperimen ini dijalankan untuk mendapat paras saliniti optima untuk pengkulturan larva serta mengkaji perkembangan organ deria dan sel klorida insang bagi larva yang dikulturkan dalam 0 dan 10 ppt. Eksperimen 1 dijalankan untuk menentukan paras saliniti optima bagi larva bermula 1-40 hari selepas penetasan (dAH) dengan paras saliniti berlainan (0, 5, 10, 15, 20, and 30 ppt). Keputusan menunjukkan 10 ppt merupakan paras saliniti optima untuk kemandiran dan tumbesaran terhadap larva bermula 1-40 larva. Tambahan pula, penggunaan *Brachionus* sp. untuk larva dapat menangani pemakanan pertama bagi larva. Dengan penemuan tersebut, kadar kematian yang tinggi pada peringkat awal larva dapat ditangani dan teknik pengkulturan dapat ditingkatkan. Eksperimen 2 dijalankan untuk menentukan saliniti optima bagi larva pada empat jangka masa pendek (1-10, 11-20, 21-30, 31-40 dAH) dengan paras saliniti yang serupa dalam Eksperimen 1. Larva untuk jangka masa 1-10dAH merupakan jangka masa yang paling kritikal dan larva mesti dikulturkan dalam 10 ppt. Keputusan juga menunjukkan larva 11-40 dAH boleh dikulturkan dalam tahap saliniti 0-30 ppt bergantung pada sumber air yang dapat diperolehi. Bagi Eksperimen 3, perkembangan organ deria diperhatikan secara histologi untuk larva yang dikulturkan dalam 0 dan 10 ppt. Perkembangan mata, telinga dalam, organ bau, tunas rasa dan neuromas bebas adalah serupa bagi larva yang diperlihara dalam 0 dan 10 ppt. Keputusan ini menunjukkan perkembangan organ deria tidak mempengaruhi kemandiran yang tinggi di 10 ppt. Bagi Eksperimen 4, perkembangan sel klorida insang ditentukan secara imunologikimia untuk larva yang diperlihara dalam 0 dan 10 ppt. Keputusan menunjukkan larva dalam 0 dan 10 ppt mempunyai pertaburan dan saiz sel klorida insang yang berlainan. Ini menunjukkan larva *O. marmoratus* berkemampuan untuk hidup dalam 10 ppt dengan bantuan sel klorida insang yang berfungsi untuk menyelaras tekanan osmotik kerana ia adalah ikan air tawar. Secara kesimpulan, 10 ppt boleh menangani kadar kematian yang tinggi pada peringkat awal larva. Keputusan kajian dapat menyumbang kepada peningkatan teknik pengkulturan larva untuk penghasilan benih *O. marmoratus*.

ABSTRACT

EFFECTS OF SALINITY ON THE SURVIVAL, GROWTH, DEVELOPMENT OF SENSORY ORGANS AND GILL CHLORIDE CELLS OF MARBLE GOBY, Oxyeleotris marmoratus LARVAE

Marble goby, Oxyeleotris marmoratus is one of the most important freshwater fish in the aquaculture industry because it has high market demand and value. The main constraint in O. marmoratus farming is insufficient seed supply due to overfishing. Another constraint is high mortality during the early larval stage under artificial rearing conditions. The experiments were conducted to obtain the optimum salinity for larval rearing and to study of the development of sensory organs and gill chloride cells of O. marmoratus larvae reared in 0 and 10 ppt. Experiment 1 was conducted to determine the optimum salinity level for larval stage from 1-40 days after hatching (dAH) with different salinity (0, 5, 10, 15, 20, and 30 ppt). The results showed that 10 ppt is the optimum salinity for survival rate and growth for O. marmoratus larval stage from 1-40 dAH. The results also revealed that the larvae can feed on the seawater rotifer, Brachionus sp. and this has solved the problem of first feeding. With these findings, the high mortality during early larval stage can be overcome and larval rearing technique can also be developed. Experiment 2 was conducted to determine the optimum salinity for the larvae reared in four shorter periods (1-10, 11-20, 21-30, and 31-40 dAH) by testing the same salinity used in Experiment 1. The rearing period 1-10 dAH was shown as the most critical period for larval survival. The results revealed that the larvae in the rearing period from 1-10 dAH must be reared in 10 ppt. The results also revealed that 11-40 dAH larvae can be reared in the salinity range of 0-30 ppt depending on available water sources. In Experiment 3, the developments of sensory organs were observed histologically for the larvae reared in 0 and I0 ppt. The development of eyes, inner ears, olfactory organs, taste buds and free neuromasts of O. marmoratus larvae were similar in larvae reared in 0 and 10 ppt. The results indicated that the development of sensory organs does not affect the high survival rate in 10 ppt. In Experiment 4, the developments of the gill chloride cells were identified immunocytochemically for the larvae in 0 and I0 ppt. The results showed that the larvae reared in 0 and 10 ppt have different distribution and sizes of the gill chloride cells. This suggested that the larvae have the ability to adapt and survive in 10 ppt with the help of their gill chloride cells that can deal with the osmotic pressure despite it being a freshwater fish. As a conclusion, 10 ppt is the optimum salinity that can overcome the high mortality of O. marmoratus during early larval stage. Results from these experiments can contribute to improve the larval rearing techniques for the mass seed production of O. marmoratus.

CONTENTS

LISTS OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ATP	Adenosine Triphosphate
ABC	Avidin Biotin Complex
BGAR	biotinylated goat anti-rabbit immunoglobulins
BSA	bovine serum albumin
C	cornea
cm	centimetre
COJ	cod oil juice
DAB	diaminobenzidine-4-HCl
dAH	days after hatching
dAO	days after ovulation
DO	dissolved oxygen
ed.	edited, edition, editor
ESD	equivalent spherical diameter
et al.	and others, and the rest
FAO	Food and Agriculture Organisation
g	gram
GCL	ganglion cell layer
h	hour
hAF	hours after fertilization
hAH	hours after hatching
HCG	human chorionic gonadotrophin
H & E	haematoxylin and eosin
HDPE	high density polyethylene
INL	Inner nuclear layer
IU	international unit
Kg	kilogram
KHz	kilo hertz
L	litre
M	metre
M^3	cubic metre
mg	milligram
min	minute

ml	millilitre
mm	millimetre
Mt	metric ton
NAP 3	Third National Agriculture Policy
NGS	normal goat serum
N.D	not detected
ON	optic nerve
ONL	outer nuclear layer
OPL	outer plexiform layer
PBS	phosphate buffer solution
PE	pigment epithelium
pH	hydrogen ion concentration
ppm	parts per million
ppt	parts per thousand
R	retina
RM	ringgit Malaysia
RNA	ribonucleie acid
s	second
sp.	species
μm	micrometre
UMS	Universiti Malaysia Sabah
UV	ultraviolet
VCL	visual cell layer

KEY WORDS

Oxyeleotris marmoratus, optimum salinity, survival, growth, sensory organs, gill chloride cells.

CHAPTER 1

INTRODUCTION

1.1. Aquaculture in Malaysia

The government of Malaysia is encouraging aquaculture under the Third National Agriculture Policy (NAP3 1998–2010) (Ministry of Agriculture Malaysia, 2000). Through aquaculture, the country can gain many advantages. Aquaculture can provide an alternative means to increase fish production to fulfill the country's protein needs instead of relying on capture fisheries (Galid, 2003; Sugiyama *et al.*, 2004). It also provides opportunities for the development of supporting industries such as the production of feed and fish fry (Ang, 1990). Furthermore, it helps to increase foreign revenue through the export market (Chua & Tech, 1990; Ministry of Agriculture Malaysia, 2000; Sugiyama *et al.*, 2004). From an environmental point of view, aquaculture not only reduces pressure on the natural resources due to overfishing, but also protects the unexplored underwater species of Malaysia (Utama & Nuruddin, 2005).

Malaysia has many good prospects to expand aquaculture industry (Ministry of Agriculture Malaysia, 2000; Galid, 2003). The country has vast potential inland areas and coastal areas, therefore both freshwater and marine aquaculture can be developed (Ang, 1990; Senoo, 2001; Department of Fisheries Malaysia, 2003). Malaysia is a tropical country, so aquaculture activities can be conducted throughout the year with little limitation of seasons (Senoo, 2001; Galid, 2003). The stable politics and economic growth have also encouraged and attracted long-term investments in aquaculture (Senoo, 2001; Sugiyama *et al.*, 2004). As a multiracial country, the aquaculture products can meet the demand without any boundaries of race, religion or ethnic group (Ang, 1990; Senoo, 2001; Galid, 2003).

In 2003, the total production of aquaculture in Malaysia was 196,874 tons valued at RM 1,172 million. From this total production, it has contributed 13.3% of the total nation's fish demand (Department of Fisheries Malaysia, 2003). It is estimated that the total production from aquaculture will increase four times from its present level by 2010 (Department of Fisheries Malaysia, 2003).

In 2003, the marine sector contributed 74% of the aquaculture production in Malaysia and the freshwater sector 26% (Department of Fisheries Malaysia, 2003). The major cultured marine species are seabass (*Lates calcarifer*), groupers (*Epinephelus* sp.), snappers (*Lutjanus* sp.), tiger prawn (*Penaeus monodon*), mud crab (*Scylla serrata*) and shellfish. Meanwhile the major cultured freshwater species are tilapia (*Tilapia* sp.), big head carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idellas*), river catfish (*Pangasius* sp., *Mystus* sp.), Javanese carp (*Puntius gonionotus*) and marble goby (*Oxyeleotris marmoratus*) (Senoo *et al.*, 1994a, 1994b; Senoo *et al.*, 1997; Department of Fisheries Malaysia, 2003).

As the Malaysian economy improves and people's standard of living escalates, it is noticeable that the demand for high economic value species is increasing (Senoo *et al.*, 1997; Senoo, 2001; Utama & Nuruddin, 2005). Among all the major cultured freshwater fishes, *O. marmoratus* is the most favoured and potential freshwater species due to its high market value and good taste (Cheah *et al.*, 1994; Senoo *et al.*, 1994a; Senoo *et al.*, 1997; Luong *et al.*, 2005).

1.2. Background of *O. marmoratus* Culture

Marble Goby, *O. marmoratus* (Figure 1.1) is the largest freshwater Eleotridae. It grows to 50 cm in total length (TL) and 2 kg in body weight (BW) (Mohsin & Ambak, 1983; Roberts, 1989; Inger & Chin, 2002). In Asian countries, this fish is also known as "Sand Goby" in English, "Ikan Ketutu" or "Ikan Hantu" in Malay and Soon Hock" or "Lam Kor" in Chinese (Senoo *et al.*, 1993a; Cheah *et al.*, 1994; Senoo *et al.*, 1997).

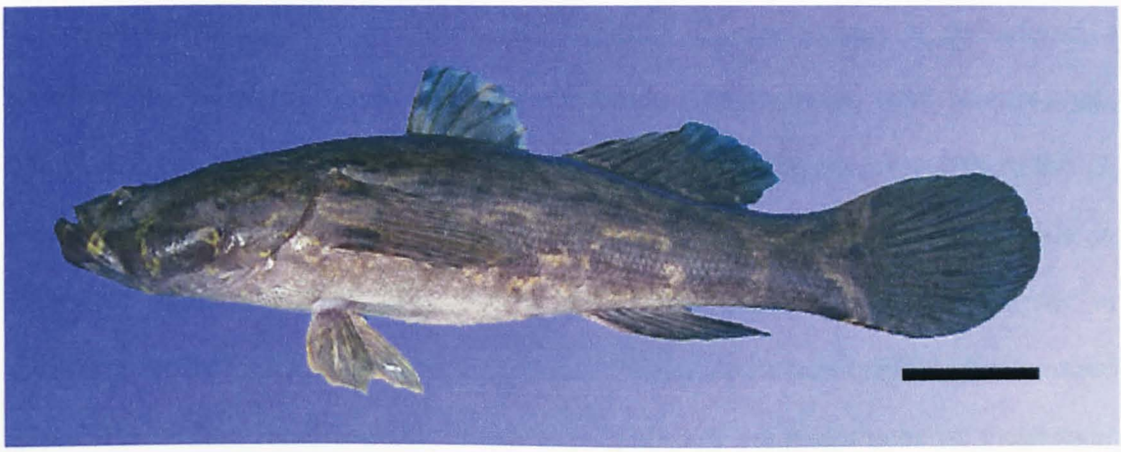

Figure 1.1: An adult female *Oxyeleotris marmoratus*, 660 g in body weight and 34.5 cm in total length. Scale bar 5 cm.

O. marmoratus is distributed throughout the Southeast Asian region such as Malaysia, Singapore, Thailand, Indonesia, Vietnam, Cambodia, Philippines and Laos and also Fiji (Mohsin & Ambak, 1983; Inger & Chin, 2002). In Malaysia, *O. marmoratus* can be found in freshwater such as rivers, lakes, small streams, paddy fields, ponds, abandoned mining pools and reservoirs (Smith, 1945; Tan & Lam, 1973; Cheah *et al.*,1994). Occasionally they can also be found in brackish water such as river mouths, swamps and mangrove areas (Kottelat *et al.*, 1993; Senoo *et al.*, 2004).

O. marmoratus is one of the most expensive freshwater fish in the Southeast Asian region due to its delicious taste (Mohsin & Ambak, 1983; Senoo *et al.*, 1993b;

Cheah *et al.*, 1994; Senoo *et al.*, 1997; Lin & Kaewpaitoon, 2000; Amornsakun *et al.*, 2003; Luong *et al.* 2005). In Malaysia, the retail price of *O. marmoratus* in major markets is RM 41.50 per kg, the highest among the other major cultured freshwater fish (Figure 1.2) (Department of Fisheries Malaysia, 2003). A survey in Kota Kinabalu, Sabah, Malaysia, showed that the price of *O. marmoratus* in seafood restaurants ranges from RM 100-120 per kg.

With the high market value and demand, *O. marmoratus* is considered a commercially important species for inland fisheries (Cheah *et al.*, 1994; Senoo *et al.*, 1994a; Amornsakun *et al.*, 2003; Luong *et al.*, 2005). In Malaysia, over 99% of the *O. marmoratus* culture is in earthen pond while only 0.56% is cultured in cages in reservoirs, lakes and rivers (Department of Fisheries Malaysia, 2003). However, in 2003, the production of *O. marmoratus* through aquaculture was only 683 tons valued at RM 8.9 million, which was the lowest (2.3%) among the major cultured freshwater fish (Figure 1.2) (Department of Fisheries Malaysia, 2003). Besides production through aquaculture, public water bodies such as rivers, ex-mining pools, dams and lakes also produced 48 tons valued at RM 1.8 million in 2003 (Department of Fisheries Malaysia, 2003).

O. marmoratus culture generally relies heavily on seed collected from the wild (Brohmanonda & Thanakumcheep, 1983). However, natural resource of *O. marmoratus* seed has decreased drastically due to overfishing while mass seed production technique has yet to be established due to high mortality at the early larval stage (Tavarutmaneegul & Lin, 1988; Ang, 1990; Senoo *et al.*, 1994a, 1994b). Therefore, the insufficient and unreliable supplies of *O. marmoratus* seeds has become the main constraint to the farming of *O. marmoratus* culture, so usually the *O. marmoratus* culture is on a very limited scale (Tan & Lam, 1973; Ang, 1990; Senoo *et al.*, 1993a, 1993b; Senoo *et al.*, 1994a, 1994b; Senoo *et al.*, 1997).

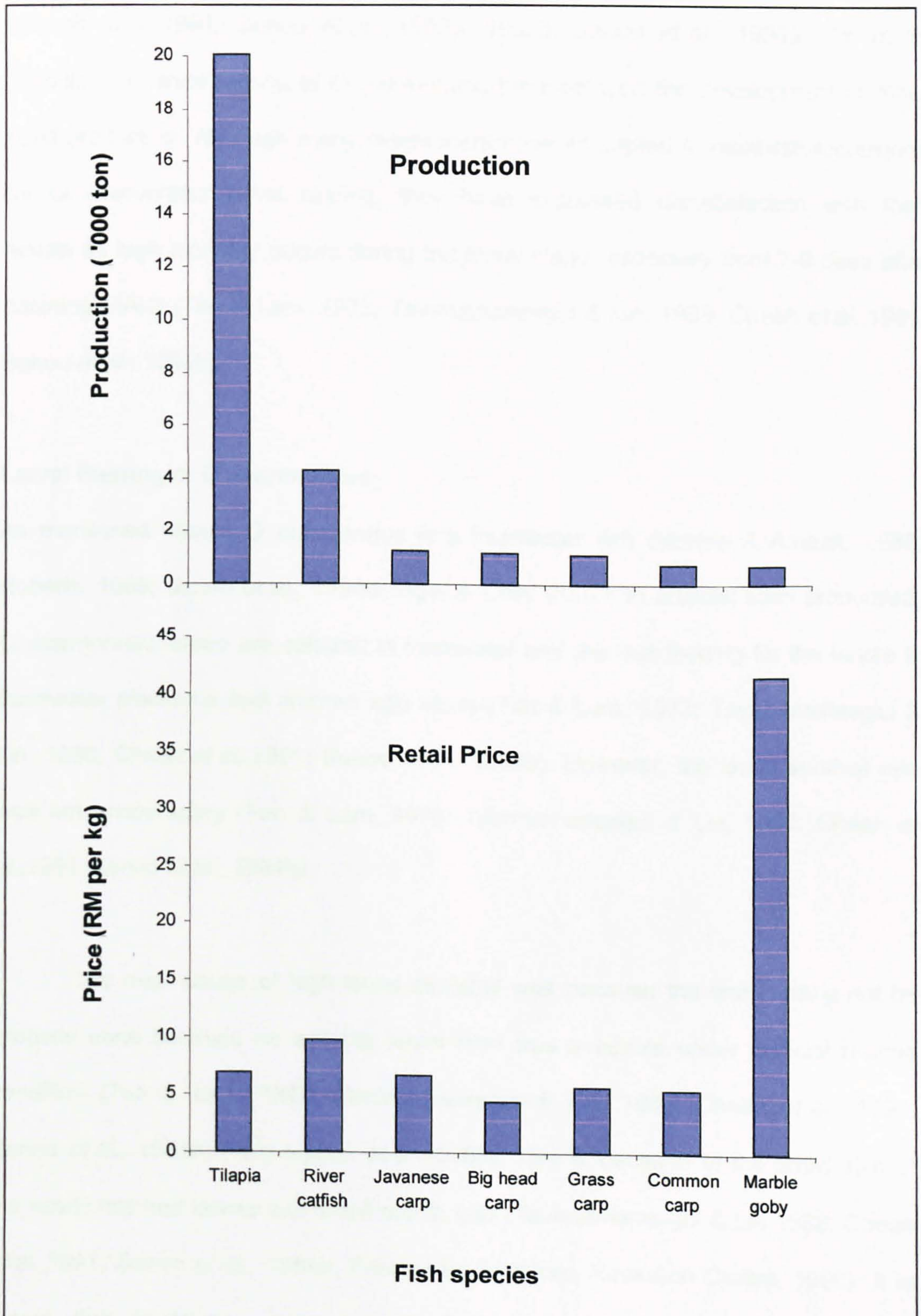

Figure 1.2: Comparison of production and retail price of some major cultured freshwater fish in Malaysia in 2003. (Source: Department of Fisheries, 2003).

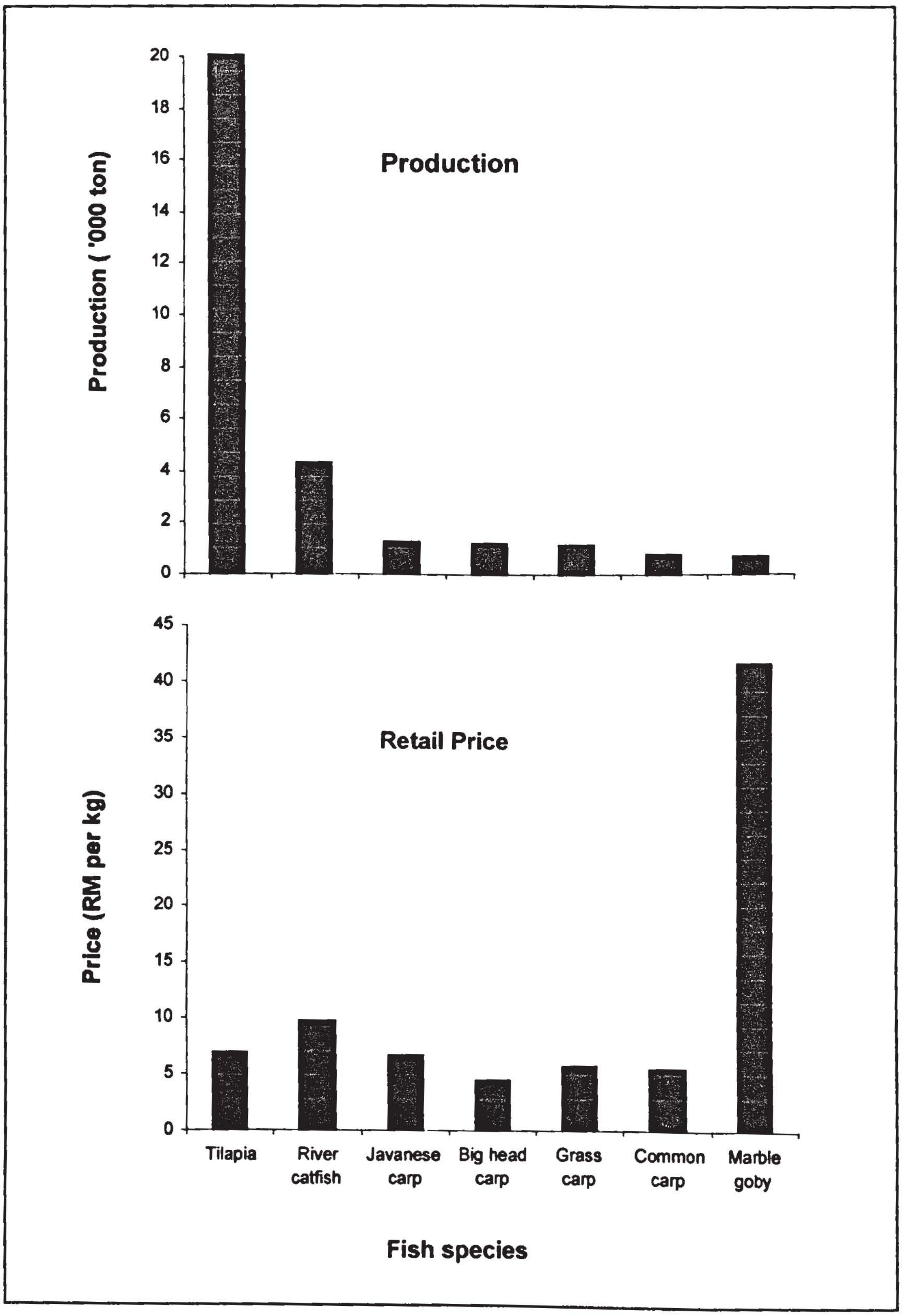

Figure 1.2: Comparison of production and retail price of some major cultured freshwater fish in Malaysia in 2003. (Source: Department of Fisheries, 2003).

REFERENCE

Amornsakun, T., Sriwatana, W. & Chamnanwech, U. 2001. Some aspects in early life stage of sand goby, *Oxyeleotris marmoratus* larvae. *6th Asian fisheries Forum book of abstracts*. pp. 7.

Amornsakun, T., Sriwatana, W. & Chamnanwech, U. 2003. The culture of sand goby, *Oxyeleotris marmoratus* I: Feed and feeding scheme of larvae and juveniles. *Songklanakarin J. Sci. Technol.* **25** (3): 367-371.

Ang, K.J. 1990. Status of aquaculture in Malaysia. *In* Joseph, M.M. (ed.). *Aquaculture in Asia*. pp. 265-279. Delhi: Asian Fisheries Society.

Ayson, F.G., Kaneko, T., Hasegawa, S. & Hirano, T. 1994. Development of mitochondrion-rich cells in the yolk-sac membrane of embryos and larvae of tilapia *Oreochromis aureus* and *O. niloticus*: (I) Biochemical and morphological changes in gill epithelium. *J.Fish Biol.* **42**: 243-254.

Baldisserotto, B. 2003. Osmoregulatory adaptations of freshwater teleosts. *In* Val, A.L. & Kapoor, B.G. (eds.). *Fish adaptations.* pp.179-196. New York: Science Publishers INC.

Blaber, S.J.M. & Blaber, T.G. 1980. Factors affecting distribution of juvenile estuarine and inshore fish. *J. Fish Biol.* **17**: 143-162.

Blaxter, J.H.S. & Hempal, G. 1963. Utilization of yolk by herring larvae. *J. Mar. Biol. Assoc.* UK. **46**: 219-234.

Blaxter, J.H.S. 1968. Rearing herring larvae to metamorphosis and beyond. *J. Mar. Biol. Assoc.* UK. **48**: 17-28.

Blaxter, J.H.S. 1986. Development of sense organs and behaviour of teleosts larvae with special reference to feeding and predator avoidance. *Trans. Am. Soc.* **115**: 98-114.

Bleckmann, H. 1986. Role of the lateral line in fish behavior. *In* Pitcher, T.J., (ed.). *The behavior of teleost fishes.* pp. 177-202. London: Croom Helm.

Boeuf, G. & Payan, P. 2001. How should salinity influence fish growth? Comparative biochemistry and physiology part C: *Toxicology and pharmacology.* **130**: 411-423.

Bone, Q., Marshall, N.B. & Blaxter, J.H.S. 1996. *Biology of fishes.* Second edition. New York: Chapman & Hall.

Bonga, W.S.E. 1997. The stress response in fish. *Physiol. Rev.***3**, 591-625.

Boonyaratpalin, S. 1981. Diseases of sand goby. *Thai Fish. GAZ.* **34**(6): 683-689.

Brohmanonda, P. & Thanakumcheep, N. 1983. Sand goby breeding. *Thai Fish. GAZ..* **36**(2): 195-206.

Cheah, S.H., Lam, S.Y. & Ang, K.J. 1991. Preliminary Report on Induced spawning of the Marble Goby, *Oxyeleotris marmoratus* in Malaysia. *Recent Innovations in the Animal and Animal Products Industry.* pp.111-114. Serdang: MSAP.

Cheah, S.H., Senoo, S., Lam, S.Y. & Ang, K.J. 1994. Aquaculture of a high value freshwater fish in Malaysia: The marble goby (*Oxyeleotris marmoratus*, Bleeker). pp. 22-25. The ICLAM Quarterly.

Chua, T.E. & Tech, E. 1990. Aquaculture in Asia: Quo vadis. *In* Joseph, M.M. (ed.). *Aquaculture in Asia.* 1st edition. pp. 13-30.Delhi: Asian Fisheries Society.

Cobcoft, J.M. & Pankhurst, P.M. 2003. Sensory organ development in cultured striped trumpeter larvae *Latris lineate: implications for feeding behaviour. Marine and freshwater research.* **54**: 669-682.

Culling, C.F.A. 1974. Handbook of histopathological and histochemical techniques. Third Edition. pp. 3-187. London: Butterworth & Co.

Department of Fisheries Malaysia, 2003. Annual Fisheries Statistics 2003. Volume 1. Jabatan perikanan Malaysia.

Evans, D.H. 1969. Studies on the permiability to water of selected marine, freshwater and euryhaline teleosts. *J. Exp. Biol.* **50**: 689-703.

Evans, D.H., Piermarini, P.M. & Potts, W.T.W. 1999. Ionic transport in the fish gill epithelium. *Journal of Experimental Zoology.* **283**: 641-652.

Febry, R. & Lutz, P. 1987. Energy partitioning in fish: The activity related cost of osmoregulation in an euryhaline cichlid. *J. Exp.Bio.* **128**: 63-85.

Fernandes, M.N. & Mazon, A.F. 2003. Environmental pollution and fish gill morphology. *In* Val, A.L. & Kapoor, B.G. (eds.) *Fish Adaptations.* pp. 203 - 225. New York: Science Publishers INC.

Freshwater Fisheries Research Centre. 1996. Annual Report.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish, *In* Hoar, W.S. & Randall, D.J. (eds). *Fish Physiology*, vol. VI. pp. 1-98. London: Academic Press.

Fuiman, L.A., Higgs, D.H. & Poling, K.R. 2004. Changing structure and function of the ear and lateral line system of fisheries during development. *American Fisheries Society Symposium* **40**:117-144.

Galid, R.S. 2003. Investment opp.ortunities in aquaculture industry in Sabah, Malaysia. *Paper presented at the 7th BIMPEAGA working group on fisheries cooperation meeting.* 10-12 June 2003, Palawan, Philipp.ines.

Guthrie,D.M & Muntz, W.R.A. 1993. Role of vision in fish behaviour. *In* Pitcher, T.J. (ed.) *The Behaviour of Teleost Fishes.* 2nd edition. pp. 89-128. London: Chapman and Hall.

Hao, H.V., Jeney, G. & Phuoc, L.H. 1996. Some haematological characteristics of sand goby (*Oxyeleotris marmoratus* Bleeker) cultured in cage in tri An Reservoir (Dong Nai Province). *WES News.* **3**: 13-14.

Hara, T.J. 1971. Chemoreception. *In* Hoar, W.S. & Randall, D.J. (eds.) *Fish physiology.* Vol.5. pp. 79-120. New York: Academic Press.

Hara, T.J. 1986. Role of olfaction in fish behaviour. *In* Pitcher, T.J. (ed.). *Behaviour of teleost fishes*. pp. 152-176. London: Croom Helm.

Hawkins, A.D. 1993. Underwater sound and fish behaviour. *In* Pitcher, T.J. (ed.) *Behaviour of teleost fishes*. 2nd edition. pp. 129-169. London: Chapman and Hall.

Herbert, B. & Graham, P. 2004. Breeding and fecundity of the endemic Australian gudgeon, sleepy cod *Oxyeleotris lineolatus* (Steindachner 1867) (Eleotridae). *Aquaculture* **236**:241-252.

Hirai, N., Tagawa, M., Kaneka, T. & Tanaka, M. 1999. Distributional changes in branchial chloride cells during freshwater adaptation in Japanese sea bass *Lateolabrax japonicus*. *Zool. Sci.* **16**: 43-49.

Hiroi, J., Kaneko, T., Uchida, K., Hasegawa, S. & Tanaka, M. 1998a. Immunolocalization of vacuolar-type H^+-ATPase in the yolk-sac membrane of Tilapia (*Oreochromis mossambicus*) larvae. *Zool. Sci.* **15**: 447-453.

Hiroi, J., Kaneko, T., Seikai, T., & Tanaka, M. 1998b. Developmental sequence of chloride clls in the body skin and gills of Japanese flounder (*Paralichtyys olivaceus*) larvae. *Zool. Sci.* **15**: 455-460.

Hiroi, J., Kaneko, T., Uchida, K., & Tanaka, M. 1999. In vivo sequential changes in chloride cell morphology in the yolk-sac membrane of Mozambique Tilapia (*Oreochromis mossambicus*) embryos and larvae during seawater adaptation. *The Journal of Experimental Biology*. **202**: 3485-3495.

Holliday, F.G.T. 1969. The effects of salinity on the eggs and larvae of teleosts. *In* Hoar, W.S. & Randall, D.J. (eds.). *Fish physiology*. pp. 293-311. New York: Academic Press.

Hollyfield, J.G., Besharse, J.C., & Rayborn, M.E. 1976. The effect of light on the quantity of phagosomes in the pigment epithelium. *Exp. Eye Res.* **23**: 623-635.

Hsu, S.M. & Raine, L. 1981. Protein A, Avidin, and Biotin in Immunohstochemistry. *Journal of histochemistry and cytochemistry*. **29**(11): 1349-1353.

Huang, W.B., Chiu, T.S. & Shih, C.T. 2000. Effects of salinity on egg and early larval characteristics of the black porgy *Acanthopagrus schlegeii. The Israeli Journal of aquaculture* **52**(2): 61-69.

Hwang, P.P., Lee, T.H., Weng, C.F. & Cho, G.Y. 1999. Presence of Na-K ATPase in mitochondria-rich cells in the yolk-sac epithelium of larvae of the teleost *Oreochromis mossambicus*. *Physiol. Biochem. Zool.* **72**:138-144.

Inger, R.F. 1955. Ecological notes on the fish fauna of a coastal drainage of North Borneo. *Op. cit.*, **37**:47-90.

Inger, R.F. & Chin, P.K. 2002. *The fresh water fishes of North Borneo*. Second edition. pp. 268. Kota Kinabalu: Natural history Publication (Borneo).

Iwai, T. 1980. Sensory anatomy and feeding of fish larvae. *In* Bardach, J.E., Magnuson, J.J., May, R. C. and Rinhart, J.M (eds.). *Fish behavior and its use in the capture and culture of fishes*. pp. 124-145. Manila: International Center For Living Aquatic Resources Management.

Janssen, J. 2004. Adaptations for the reception of natural stimuli. Lateral line sensory ecology. *In* Emde, G., Mogdans, J. and Kapoor, B.G. (eds) *The senses of fish.* pp. 231-264. Delhi: Narosa Publishing House.

Jayaram, K.C. 1999. The freshwater fishes of the Indian Region. Delhi: Narendra Publishing House.

Jee, A.K. 1980. Some problems in the cage culture of marble goby (*Oxyeleotris marmorata* Bleeker). *Aquaculture* **20** (3), 229.

Johnson, D.W. & Katavic, I. 1986. Survival growth of sea bass (*Dicentrarchus labrax*), larvae as influenced by temperature, salinity and delayed initial feeding. *Aquaculture* **52**: 11-19.

Jonna, R. & Weinheimer, M. 2003. "Eleotridae" (On-line), *Animal Diversity Web.* Accessed September 04, 2005 http://animaldiversity.ummz.umich.edu/site/accounts/information/Eleotridae.html

Karnaky, K.J., Jr. 1980. Ion secreting epithelia: Chloride cells in the head region of Fundulus heteroclitus. *AM.J. Physiol.* **238**: 185-198.

Karnaky, K.J., Jr. 1992. Teleost Osmoregulation: Changes in the tight junction in response to the salinity of the environment. *In* Cereijido, M. (ed.). *Tight Junction* pp. 175-185. Florida: CRC Press.

Karnaky, K.J., Jr. 1997. Osmotic and Inonic Regulation. *In* Evans, D. H. (ed.). *The physiology of fishes.* Second edition. pp. 157-178. New York: CRC press.

Kawamura, G., Kadowaki, S. & Mukai, Y. 1984. Behaviour and eye development during larval stages of the Japanese parrotfish. *Min. Rev. Data File Fish. Res.*, **3**: 45-48.

Kawamura, G. & Ishida, K. 1985. Changes in sense organ morphology and behaviour with growth in the Flounder *Paralichthys olivaceus. Bulletin of the Japanese Society of Scientific Fisheries.* **51**(2), 155-165.

Kawamura, G. & Washiyama, N. 1989. Ontogenetic changes in behavior and sense organ morphogenesis in largemouth bass and *Tilapia nilotica. Transactions of American Fisheries Society.* **118**: 203-213.

Kawamura, G., Mori, H. & Kuwahara, A. 1989. Comparison of sense organ development in wild and reared flounder *Paralichthys olivaceus* larvae. *Bulletin of the Japanese society of scientific fisheries.* **55**(12): 2079-2083.

Kirschner, L.B. 1980. Comparison of vertebrate salt excreting organs. *Am. J. Physiol.* **7**: 219-223.

Kotrschal, K., Adam, H., Brandstatter, R., Junger, H., Zaunreiter, M. & Goldschmid, A. 1990. Larval size constraints determine directional ontogenetic shifts in the visual system of teleosts. *Zool. Syst. Evolut-forsch.* **28**: 166-182.

Kottelat, M., Whitten, A.J., Kartikasari, S.N. & Wirjoatmodjo, S. 1993. *Freshwater fishes of Western Indonesia and Sulawesi.* pp. 221.Hong Kong: Periplus Editions.

Kunz, Y.W. 2001. Development of the eye of teleost. *In* Kapoor, B.G. and Hara, T.J. (eds.). *Sensory biology of jawed fishes new insight.* pp. 1-18. London: Science Publishers.

Lam, K., Tsui, T., Nakano, K. & Randall, D.J. 2006. Physiological adaptations of fishes to tropical intertidal environments. *In* Val, A.L., Almeida, V.M.F. and Randall, D. (eds.) *The Physiology of tropical fishes.* Volume 21. pp. 502-562. The Netherlands: Elsevier Academic publishers.

Lankford, T.E. & Targett, Jr. T.E. 1994. Suitability of estuarine nursery zones for juvenile weakfish (*Cynoscion regalis*): effects of temperature and salinity on feeding, growth and survival. *Mar. Biol.* **119**: 611-620.

Langdon, J.S. 1987. Active osmoregulation in the Australian bass, *Macquaria novemaculeata* (Steindachner), and the golden perch, *Macquaria ambigua* (Richardson) (Percichthyidae). *Aust.J. Mar. Freshwater Res.* **38**: 771-776.

Lasserre, P. 1971. Increase of (NA^{+}+ K^{+}) dependent ATPase activity in gills and kidneys of two teleosts, *Crenimugil labrosus* (Risso, 1826) and *Dicentrarchus labrax* (Linnaeus, 1758), during adaptation to freshwater. *Lif Sci.* **10**: 113-119.

Laurent, P. & Perry, S.F. 1991. Environmental effects on fish gill morphology. *Physiol. Zool.* **64**: 4-25.

Lin, K.J., Chen, C.L., Juang, C.Y. & Yen, C.L. 1987. The mass production of fingerlings and effect of salinity on the survival and growth of black sea bream, *Acanthopagrus schlegeli* (Bleeker). *Butt. Taiwan Fish. Res Inst.* **42**: 345-356.

Lin, C.K. & Kaewpaitoon, K. 2000. An overview of freshwater cage culture in Thailand. Cage Aquaculture in Asia: *Proceedings of the First International Symposium on Cage aquaculture in Asia.* (Lin, C.K., Ed). pp. 253-257.

Lin, H. & Randall, D. 1995. Proton pumps in fish gills. *In* Wood, C.M and Shuttleworth, T.J. (eds.) *Cellular and molecular approaches to fish ionic regulation.* pp. 229-250. New York: Academic Press.

Lopez, V.G, Martinez, K.M. & Garcia, M.M. 2004. Effects of temperature and salinity on artificially reproduced eggs and larvae of the leopard grouper *Mycteroperca rosacea. Aquaculture.* **237**: 485-498.

Lowenstein, O. 1971. The labyrinth. *In* Hoar, H.S. and Randell, D.J. (eds). *Fish physiology.* Vol. 5. pp. 207-240. New York: Academic Press.

Lubin, R.J. 1989. Ultrastructural alterations in branchial chloride cells of Atlantic Salmon, *Salmo salar* during parr-smolt transformation and early development in seawater. *J. Fish Biol.* **34**: 259-272.

Luong, V.C., Yang, Y. & Lin, C.K. 2005. Cove culture of marble goby (*Oxyeleotris marmorata* Bleeker) and carps in Tri An Reservoir of Vietnam. *Aquaculture* **244**: 97-107.

Lubzens, E. & Zmora, O. 2003. Production and nutritional value of rotifers. *In* Stottrup, J.G. & McEvoy, L.A. (eds). *Live feeds in marine aquaculture.* pp. 18-63. London: Blackwell Publishing.

Madsen, S.S., McCormick, S.D., Young, G., Endersen, J.S., Nishioka, R.S. & Bern, H.A. 1994. Physiology of seawater acclimation in the striped bass, *Morone saxatilis* (Walbaum). *Fish physiol.* **98**: 323-326.

Mancera, J.M., Perez-Figares, J.M. & Fermandez-Llebrez, P. 1993. Osmoregulatory response to abrupt salinity changes in the euryhaline gilthead sea bream (*Sparus aurata*). *Comp. Biochem. Physiol.* **106a**: 245-250.

Marshall, W.S. 1995. Transport processes in isolated teleost epithelia: opercular Epithelium and urinary bladder. *In* Wood, C.M and Shuttleworth, T.J. (eds.). *Cellular and molecular approaches to fish ionic regulation.* pp. 1-19. New York: Academic Press.

Marshall, W.S., Emberley, T.R., Singer, T.D., Bryson, S.E. & McCormick, S.D. 1999. Time course of salinity adaptation in a strongly euryhaline estuarine teleost, *Fundulus heteroclitus*: A multivariable approach. *The Journal of Experimental Biology.* **202**: 1535-1544.

Masuda, H., Amaoka, K., Araga, C., Uyeno, T. & Yoshino, T. 1984. The fishes of the Japanese archipelago. pp. 33-288. Tokai: Tokai University.

McCormick, S.D. 1995. Hormonal control of gill Na^+, K^+-ATPase and chloride cell function. *In* Wood, C.M and Shuttleworth, T.J. (eds). *Cellular and molecular app.roaches to fish ionic regulation*). pp. 285-307. New York: Academic Press.

Ministry of Agriculture. 2000. 'Opp.ortunities in Agriculture' NAP3-A Comprehensive App.roach Towards Agricultural Development in Malaysia. *Persidangan Tahunan MANCID Ke8 (8th MANCO)*, 23-24 November, 2000

Mohsin, A.K.M & Ambak, M.A. 1983. *Freshwater fishes of Peninsular Malaysia*. pp. 284. Serdang: Universiti Pertanian Malaysia.

Morgan, J.D. & Iwama, G.K. 1999. Energy cost of NaCl transport in isolated gills of cutthroat trout. *Am J Physiol.* **277**: 631-639.

Moser, M.L. & Gerry, L.R. 1989. Differential effects of salinity changes on two estuarine fishes, *Leiostomus xanthurus* and *Micropogonias undulatus. Estuaries.* **12**: 35-41.

Mukai, Y. & Kobayashi, H. 1992. Cupular growth rate of free neuromasts in three species of cyprinid fish. *Nipp.on Suisan Gakkaishi* **58** (10): 1849-1853.

Mukai, Y., Kobayashi, H. & Yoshikawa, H. 1992. Development of free and canal neuromasts and their directions of maximum sensitivity in the larvae of Ayu, *Plecoglossus altivelis. Japanese journal of ichthyology.* **38** (4): 411-417.

Mukai, Y. & Kobayashi, H. 1993. Extremely long cupulae of embryonic neuromasts in cyprinid fish. *Copeia.* **4**: 1157-1159.

Mukai, Y. & Kobayashi, H. 1994. Development of free neuromasts in larvae of cyprinid fish. Mem.*Fac.Agr.* Kinki Univ. **27**:1 -14.

Mukai, Y. 2006. Role of free neuromasts in larval feeding of Willow shiner *Gnathopogon elengatus caerulescens* Teleostei, Cyprinidae. *Fisheries science.* **72**: 705-709.

Myers, G.S. 1949. Salt–tolerance of fresh-water fish groups in relation to zoogeographical problems. *Bijtr.tot Dierk.* **28**: 315-322.

Noakes, D.L.G. & Godin, J.G.J. 1988. Ontogeny of behavior and concurrent developmental changes in sensory systems in teleost fishes. *In* Hoar, W.S. and Randall, D.J. (eds). *Fish physiology* (Volume XI). pp. 345-384. London: Academic Press.

Norman, J.R. 1999. A history of fishes (A complete known account of fishes)-Condition of life. pp. 230-251. Delhi: Agro Botanical publishers.

Panha, S. 1992. Infection experiment of the glochidium of a freshwater pearl mussel, *Hyriopsis (Limnoscapha) myersiana* (Lea, 1856). *Japanese journal of malacology.* **51**(4): 303-314.

Partridge, G.J. and Jenkins, G.I. 2002. The effect of salinity on growth and survival of juvenile black bream (*Acanthopagrus butcheri). Aquaculture* **210**: 219-230.

Pasookdee, S. & Sirikul, C. 1983. Nursing sand goby fry. *Thai Fish. GAZ.* **36**(1): 55-59.

Perry, S.F. 1998. Relationships between branchial chloride cells and gas transfer in freshwater fish. *Comp. Biochem. Physioal.* **119A**: 9-16.

Peterson, M.S., Comyns, B.H., Rakocinski, C.F. & Fulling, G.L. 1999. Does salinity affect somatic growth in early juvenile Atlantic croaker, *Micropogonias undulates (L)? J. Exp. Biol.* **238**: 199-207.

Pisam, M. & Rambourg, A. 1991. Mitochondria-rich cells in the gill epithelium of teleost fishes: an ultrastructural app.roach. *Int. Rev. Cytol.* **130**: 191- 233.

Popp.er, A.N. & Coombs, S. 1980. Acoustic detection by fishes. In Ali, M.A. (ed.) *Environmental physiology of fishes.* pp. 403-430. New York: Plenum.

Roberts, T.R. 1989. *The freshwater fishes of Western Borneo* (Kalimantan Barat, Indonesia). pp. 210. San Francisco: California Academy of Sciences.

Rombough, P.J. 1999. The gill of fish larvae. Is it primarily a respiratory or an ionoregulation structure? *Journal of fish Biology* **55**: 186-204.

Sasai, S., Kaneko, T. & Tsukamoto, K. 1998. Extrabranchial chloride cells in early life stages of Japanese eel, *Anguilla japonica. Ichthyol. Res.* **45**: 95-98.

Schellart, N.A.M. & Wubbels, R.J. 1998. The auditory and mechanosensory lateral line system. *In* Evans, D. H. (ed.). *The physiology of fishes.* Second edition. pp. 283-312. Florida: CRC Press LLC.

Senoo, S., Cheah, S.H. & Ang, K.J. 1992. Spawning the ketutu. *Malaysian Fisheries Society Fishmail.* **4**(2):3-5.

Senoo, S., Ang, K.J. & Cheah, S.H. 1993a. Deformations of marble goby *Oxyeleotris Marmora* seeds reared under tank condition. In Abstract of *Fisheries and the Environmental. Beyond 2000*, pp. 55. Serdang: Universiti Pertanian Malaysia.

Senoo, S., Cheah, S.H. & Ang, K.J. 1993b. Natural spawning of marble goby, *Oxyeleotris marmoratus* under artificial condition. *Malaysia Fisheries Society Fishmail* **5**(3):16-18.

Senoo, S., Kaneko, M., Cheah, S.H. & Ang, K.J. 1994a. Artificial Seed production techniques of marble goby, *Oxyeleotris marmoratus:* Aquaculture practice in Malaysia, *Malaysia Fisheries Society* (29-30 March 1994).

Senoo, S., Ang, K.J. & Kawamura, G. 1994b. Development of sense organs and mouth and feeding of reared marble goby *Oxyeleotris marmoratus* larvae. *Fisheries Science.* **60**(4): 361-368.

Senoo, S., Kaneko, M., Cheah, S.H. & Ang, K.J. 1994c. Egg development, hatching, and larval development of *marble goby, Oxyeleotris marmoratus* under rearing conditions. *Fisheries Science.* **60**(1): 1-8

Senoo, S., Ang, K.J. & Cheah, S.H. 1997. Egg collection from small-sized Marble Goby, *Oxyeleotris marmoratus* by natural spawning method in tanks. In Japar Sidik, B,F.M. Yussoff, T.Petr and Mohd Zaki M.S. (eds.). *Fisheries and the Environment Beyond 2000.* pp. 251-256. Serdang: Universiti Putra Malaysia.

Senoo, S. 2001. Aquaculture status and the diverse social background in Malaysia (Fish culture in Southeast Asia 1). *AquaNet.* **4**: 68-72.

Senoo, S. 2003. Artificial seed production of marble goby, Oxyeleotris marmoratus –II. Fish culture in Southest Asia 30. *AquaNet.* **9**:66-71.

Senoo, S., Mukai, Y., Ooi, P.T. & Rahman, R.A. 2004. Good effects of brackish ater for the larval rearing of marble goby, *Oxyeleotris marmoratus.* In Conference of Japanese Society of Fisheries Science at Kagoshima University.

Shariff, M. 1982. *Henneguya shaharini* sp. nov. (Protozoa: Myxozoa), a parasite of Marble Goby, *Oxyeleotris marmoratus* (Bleeker). *Journal of fish diseases.* **5**(1): 37-45.

Smith, H.M. 1945. The freshwater fishes of Siam or Thailand. pp. 622. New York: Printing press.

Stagg, R.M. & Shuttleworth, T.J. 1982. Na^+, K^+-ATPase, ouabain binding and ouabain sensitive oxygen consumption in gill from *Platichthys flesus* adapted to seawater and freshwater. *J.Cell. Physiol.* **147**: 93-99.

Sugiyama, S., Staples, D. & Funge-Smith, S.J. 2004. *Status and potential of Fisheries and Aquaculture in Asia and the Pacific.* FAO Regional Office for Asia and the Pacific 2004/05.53. Bangkok: RAP Publication.

Swanson, C. 1996. Early development of milkfish: effects of salinity on embryonic and larval metabolism, yolk absorption and growth. *J. Fish Biol.* **48**: 405-421.

Tagliafierro, G. & Zaccone, G. 2001. Morphology and immunohistochemistry of taste bud in body fish. *In* Kapoor, B.G and Hara, T.J. (eds.). *Sensory biology of jawed fishes* pp. 335-345.New York: Science publishers.

Takita, T. 1975. Spawning and embryonic development of *Synechogobius hasta* in an aquarium with description of larvae and juveniles. *J. Ichthyol.* Japan **22**:31-39.

Tan, O.K.K. & Lam, T.J. 1973. Induced Breeding and Early Development of the Marble Goby (*Oxyeleotris marmoratus*, BLK). *Aquaculture* **2**:411-423.

Tandler, A., Anav, F.A. & Choshniak, I. 1995. The effect of salinity on growth rate, survival and swimbladder inflation in gilthead seabream, *Sparus aurata*, larvae. *Aquaculture* **135**: 343-353.

Tavarutmaneegul, P. & Lin, C. K. 1988. Brearing and Rearing of sand goby (*Oxyeleotris marmoratus*, BLK). *Aquaculture* **69**: 299-305.

Treece, G.D. & Davis, D.A. 2000. Culture of small zooplankters for the feeding of larval fish. *Southern Regional Aquaculture Center Publication*. No. 701.

Tytler, P. & Blaxter, J.H.S. 1988. The effects of external salinity on the drinking rates of larval herring (*Clupea harengus*), plaice (*Pleuronectes platessa*) and cod (*Gadus morhua*). *Journal of Experimental Biology* **138**: 1-5.

Tzeng, W.N., Lizuka, Y., Shiao, J.C., Yamada, Y. & Oka, H.P. 2003. Identification and growth rates comparison of divergent migratory contigents of Japanese eel (*Anguilla japonica*). *Aquaculture* **216**:77-86.

Uchida, K., Kaneko, T., Yamauchi, K. & Hirano, T. 1996. Morphometrical analysis of chloride cell activity in the gill filaments and lamellae and changes in Na^+, K^+-ATPase activity during seawater adaptation in chum salmon fry. *Journal of Experimental Zoology*. **276**:193-200.

Ujang Komarudin A.K. 2000. BETUTU: Pemikahan secara alami,& induksi, pembesaran di kolam, keramba & hampang. Jakarta: Penebar Swadaya.

Ura, K., Soyana, K., Omoto, N., Adachi, S. & Yamauchi, K. 1996. Localization of Na^+, K^+-ATPase in tissues of rabbit and teleosts using an antiserum directed against a partial sequence of the α-sununit. *Zoology Science*. **13**: 219-227.

Utama, C.M. & Nuruddin, A.A. 2005. Trash fish production and national fish feed requirement in Malaysia. Regional workshop on low value and "Trash Fish" in the Asia-Pacific Region, Hanoi, Viet Nam. 7-9 June.

Wheeler, A. 1998. Field key to the freshwater fishes and lampreys of the British Isles. *Field Studies* **9**: 355-394.

Wootton, R.J. 1998. Ecology of teleost fishes. Second edition. pp. 5-86. The Netherlands: Kluwer Academic Publishers.