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THESIS

POPULATION AND REPRODUCTIVE BIOLOGY OF SHARK CATFISH AND ITS FISHERIES IN THE MUN RIVER, THAILAND

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Shark catfish, *Helicophagus waandersii* Bleeker, was a group-synchronous spawner with a short spawning season from May to July and spawned at least two times per lifespan. Average fecundity was 85,174±43,206 eggs/fish. The first mature size of female was 27.36 cm while the effective range to be a good spawner was 38.56-45.46 cm that gave the length of 50% maturity at 42.01 cm.

Shark catfish started moving from the Mekong mainstream since January and developed the eggs in the Mun River. The spawning ground was covered from Kang Tana through Kang Sapue rapids. After spawning, parental stock moved back to deep pools in the Mekong mainstream whereas the juvenile moved farther to the floodplain at Sawang Weerawong District for nursing and feeding purposes. Then it moved backward and joins with adult stock in September.

The growth pattern of this species was isometric with non-seasonal growth. The growth parameters were; $L_\infty = 59.74$ cm, $K = 1.32$/year and $W_\infty = 1,415.2$ g. The longevity was varied from two years and four months to three years. The recruitment pattern was prolonging period with a prominent peak during March to August.

The mortality coefficients were $Z=4.863$, $M=1.7853$ and $F=3.078$/year, and exploitation rate was 0.63. The exploitation rate of shark catfish in the Mun River was nearly reaches the MSY but over the MSE. For the maximum profit management of shark catfish fisheries in the Mun River, it should reduce the exploitation ratio down to 8% at MSE level.

The optimum length for being caught (L_c) of gillnets and bottom longlines were 29.56 cm and 28.55 cm, respectively. For management purpose, fishermen should use the mesh size bigger than 5.5 cm for gillnet and hook size smaller than no. 17 in the open water zone apart from the spawning and nursing ground along the Mun River. That covered from Kang Tana rapids through Kang Sapue rapids and aware the floodplain in Sawang Weerawong District as a nursery protected areas during the closed fishing season.

Student's signature

Thesis Advisor's signature

14 / 3 / 06

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Monica Thanitha Thapanand

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DEDICATED TO THE LOVING MEMORY OF TWO PERSONS WHOM I FOREVER ADMIRE

My beloved aunt

Assoc. Prof. Salag Dhabanandana, Ph.D. (Phy. Chem.)

1933 - 2000

Just want to tell you that, I can feel your happiness that our dreams come true even you couldn’t share it with me on earth

and

Assoc. Prof. Prichar Sommani, Ph.D. (Fisheries)

1942 – 1994

My ‘fingerprint’ and ‘inspiration’ to be a ‘Professional Fishery Biologist’

AND

A SPECIAL PERSON WHOM HIS WORDS ‘PENETRATED’ MY HEART

Prof. Albert Einstein, Ph.D. (Physics)

1879 - 1955

“Politics is for the moment; an equation is for eternity.”

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LIST OF ABBREVIATIONS

11-KT = 11-ketotestosterone

17α-P = 17α-hydroxyprogesterone

17, 20-P = 17α, 20 β-dihydroxy-4-pregnen-3-one

17-OH-P = 17α-hydroxyprogesterone

20β-HSD = 20β-hydroxysteroid dehydrogenase

a = Y-intercept of the linear regression equation

APHA = American Public Health Association

at = Atresia

b = Slope of the linear regression equation

BW = Body Weight

$\bar{B}/R$ = Average biomass per recruit

c = Constant of length-weight relationship

C_{aL} = Catch in number of m_a mesh size

C_{bL} = Catch in number of m_b mesh size

$C(L, L_\alpha)$ = The cumulative catch of fish of length L

CPUE = Catch per Unit of Fishing Effort

DO = Dissolved Oxygen

DoF = Department of Fisheries

E = Exploitation ratio

E_2 = 17 β-œstradiol

ef = Empty follicle

EGAT = Electronic Generation Authority of Thailand

EIA = Environmental Impact Assessment

ELEFAN-1 = Electronic Length Frequency Analysis-1

ev = Early vitellogenic stage

FAACC = Formalin Acetic Acid Calcium-Chloride solution

FiSAT = Fish Stock Assessment Tools

F = Instantaneous fishing mortality coefficient

Fe = Fecundity

F_L = Fishing mortality at each length class

F_{max} = Maximum Fishing mortality

GSI = Gonadosomatic Index

GtH = Gonadotropin Hormone

GW = Gonad Weight

%IRI = Percentage Index of Relative Importance

K = Growth constant

KU = Kasetsart University

L_∞ = Asymptotic length

L_c = Optimum length for being caught

L_{fm} = Length at first mature

L_m = Length at 50% maturity

L_{ma} = Optimum length for being caught at m_a mesh size

L_{mb} = Optimum length for being caught at m_b mesh size

L_r = Length at first recruitment

L_t = Length at time ‘t’

LFD = Length Frequency Distribution

LMS = Lower Mekong Migration System

M = Instantaneous natural mortality coefficient

m_a = An ‘a’ cm mesh size

m_b = A ‘b’ cm mesh size

MGC = Mekong giant catfish

MIH = Maturation Inducing Hormone

MMS = Middle Mekong Migration System

MSE = Maximum Sustainable Economic Yield

MSL = Mean Sea Level

MSY = Maximum Sustainable Yield

n = Exponent of length-weight relationship

N_{aL} = Index of the number in the population for m_a mesh size

N_{bL} = Index of the number in the population for m_b mesh size

NGO = Non-Government Organisation

NIFI = National Inland Fisheries Institute

ϕ' = Relative growth performance

P_{Fe} = Proportion of fecundity frequency

P_L = Proportion of mature female

po = Primary oocyte

pvf = Post-vitellogenic follicle

Rf = Rainfall

R_n = Goodness of fit index

S = Standard deviation

S_{aL} = Standard deviation of m_a mesh size

S_{bL} = Standard deviation of m_b mesh size

SF = Selection Factor

SL = Standard Length

t = Time

t_0 = Arbitrary age at length zero

t_c = Age at first capture

t_{max} = Maximum age or longevity

t_r = Age at recruitment

Tb = Turbidity

T = Testosterone

TL = Total Length

UBU = Ubon Ratchathani University

UMS = Upper Mekong Migration System

v = Vitellogenic stage

VBGF = von Bertalanffy’s Growth Function

VPA = Virtual Population Analysis

VTG = Vitellogenin

W = Weight

W_∞ = Asymptotic body weight

$\left(Y/R\right)'$ = Relative yield per recruit

Z = Instantaneous Total Mortality Coefficient

POPULATION AND REPRODUCTIVE BIOLOGY OF SHARK CATFISH AND ITS FISHERIES IN THE MUN RIVER, THAILAND

INTRODUCTION

The Mun River, a part of the Mekong River basin, has a catchment area of 117,000 km^2. It is the longest river in the northeastern region and also the largest Mekong tributary in Thailand. The confluent area of Mun River to Mekong is Khong Jiem District, Ubon Ratchathani Province. The total length of the river is 641 km and runs through 11 provinces (Doungsawasdi and Chookajorn, 1991; Amornsakchai *et al.*, 2000). There are three densely populated communities along the Mun riverbanks: Warin Chamrab, Ubon municipality and Phibun Mangsahan. Inhabitants use the river for many purposes *i.e.* domestic uses, agriculture, livestock raising, fisheries, industries, transportation and recreation (Amornsakchai *et al.*, 2000).

Most fish species in the Mekong river system show the migratory habit albeit to a different degree (Warren and Mattson, 2000). Northcote (1984) stated that migratory behaviour of riverine fishes depend on the separation in space and time of optimal habitats for growth, survival and reproduction. It also occurs with a periodicity (Smith, 1985). In the Mekong River and tributaries, the fish migration occurs twice a year (MRC, 2002). Firstly, in wet-season (May through October), which major fish migration are pangasiids and silurids (Baird *et al.*, 2000a; Baird *et al.*, 2000b; Baird *et al.*, 2001). Secondly, in dry-season (November through April), which are mostly cyprinids (Warren *et al.*, 1998; Warren, 1999; Baird *et al.*, 2000a). Many of them migrate long distances and often across international borders. All fish are also vulnerable to impact from development, including transboundary impacts. A long-distance migratory species are particularly vulnerable because they depend on many different habitats which require migration corridors among different habitats (MRC, 2002).

Impounding of river generally changes the natural water flow, water quality and thermal regime. It is also a physical barrier to the migration of fish. The ecosystem will change from riverine to lacustrine type from time to time (Gray *et al.*, 2000). Some riverine species cannot adapt themselves to reproduce within lacustrine condition and need spawning migration (De Silva, 1983; Tomasson *et al.* 1984).

Blocking of spawning migratory route, especially dam construction, causes the stock depletion and extirpates the migratory population (Roberts, 2001a). In the Mekong River basin, many hydropower generation projects are set up, for example; Don Sahang and Theun Hinbourn in Lao PDR (Mekong Secretariat, 1992; Warren, 1999); the Lanchang Project in Yunan, China (Roberts, 2001a), and the Pak Mun Project in Thailand (Roberts and Warren, 1994; Schouten *et al.*, 2000; Roberts, 2001b) (Figure 1).

The Pak Mun Dam, a run-of-the-river type, was built by Electricity Generation Authority of Thailand (EGAT) and has operated since 1994. The dam blocks the Mun River at six-km upstream from the Mun-Mekong confluence (Jutagate *et al.*, 2001). Schouten *et al.* (2000) mentioned that after the dam is operated, fish and fisheries have been haphazard leaving. In addition, the performance of fishpass should pre- and post- study with properly evaluation. For the Pak Mun case, pool and weir type fishpass was superficially constructed without any feasible study until the report of Polprasit *et al.* (1997a and b). They reported that 63 fish species in 15 families or more than 50 percent of fish in the Mekong and the Mun River could move upstream by passing fishpass. In contrast with the report of Sripatraprasit and Lin (2003), 51 fish species passed the fishpass for upstream migration whereas 29 fish species passed for downstream migration. Fish samples from the both directions were small size and undeveloped gonad.

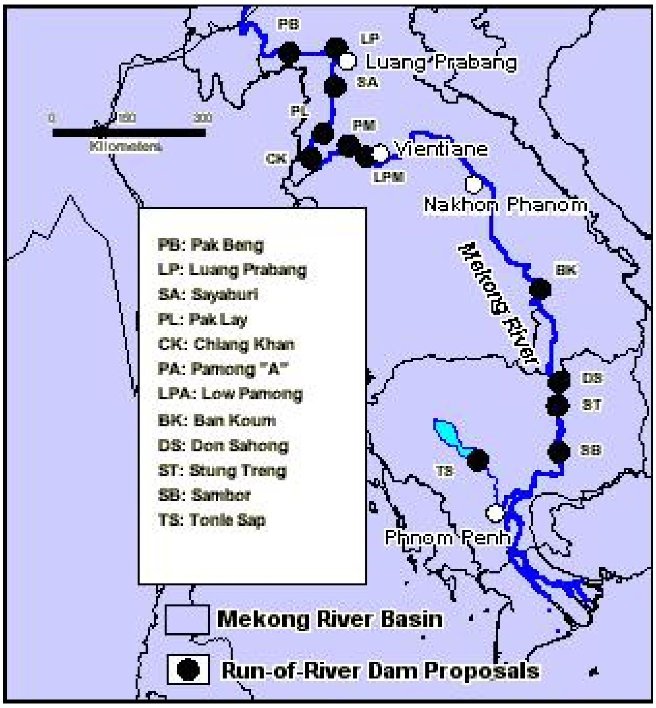


Figure 1 Run-of-the-river hydropower dams in the Lower Mekong Basin
Source: http://www.usyd.edu.au/su/geography/hirsch/5/5.htm, 27 Feb. 2006

Construction of Pak Mun Dam has become one of the vital controversies in Thailand since 1990. NGOs, especially the Assembly of the Poor and local fishermen petitioned the EGAT to open the sluice gates in the rainy season. They referred to their experiences that, fish migrates upstream from Mekong to spawn during that time. They also alleged that fishpass does not help fishes having successfully spawning migration (Jutagate, *et al.*, 2003). From the stated argument, the way to solve this problem is to verify the spawning migratory pattern of fish. Unfortunately, reproductive biology and migratory behaviour of potamodromous fish in the Mun River is not well studied.

For the environmental signals, Balon (1975) suggested that the most important factor for breeding success is optimum dissolved oxygen (DO). Other related factors are temperature, turbidity, pH, ammonia, nitrate, and rainfall. All of these factors will stimulate reproductive and migratory activities of fish. (Herzig and Winter, 1986; Burkhalter and Kaya, 1977; Lewis and Morris, 1986). It is necessary to study reproductive biology related to the environmental signals to clarify the type of fish migration instantly.

Among the economic potamodromous fishes, shark catfish (*Helicophagus waandersii* Bleeker, 1858) is one of the major species captured in the Mun River (Figure 2). Nowadays, the reproductive biology and fishery status of the species in this area have not been studied. The local fishermen claim that this species cannot pass the fishpass to spawn upstream (Chaiwut Grudpan and riparian fishermen, *pers. com*.). It is caught all year round both upstream and downstream areas with different magnitude of catching (Jutagate *et al*, 2005). This study attempts to investigate the spawning migration of shark catfish as a representative of potamodromous fish in the Mun River. The output of this study may investigate the evidence of spawning migration in relation to environmental signals. Moreover, the fishery status, management and assessment will be useful to propose management measures for effective management in the near future.

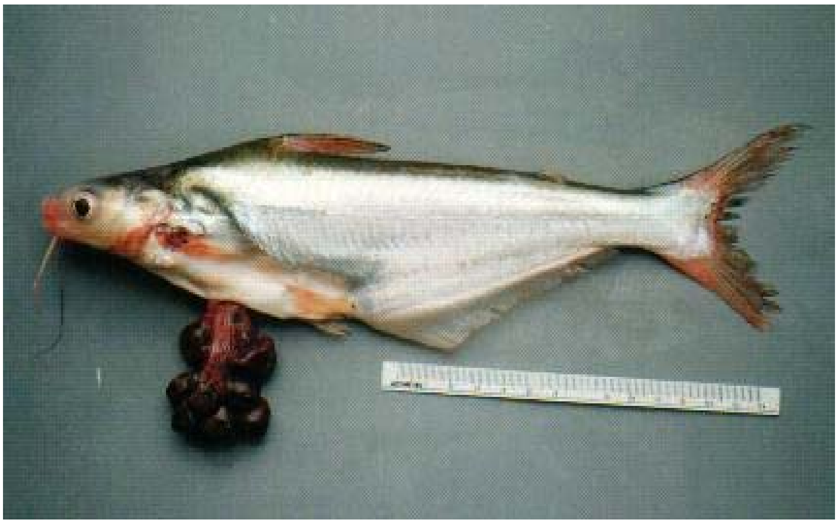


Figure 2 Shark catfish, *Helicophagus waandersii* Bleeker, 1858

The objectives of this study are:

1. To estimate population parameters;

2. To study the reproductive biology of shark catfish covering histology, fecundity, gonadosomatic index and sex steroid hormones;

3. To monitor some water qualities which stimulate reproductive activities;

4. To investigate the migratory route of shark catfish; and

5. To propose fishery management measures for shark catfish such as the optimal mesh sizes of fishing gear *viz.* gillnet and longline as well as estimate the optimum length for being caught, stock size and relative yield per recruit that corresponding to the exploitation rate.

LITERATURE REVIEW

1. Spawning Migration of Fish

Fish movements take place at every stages of life for its appropriate habitat. Northcote (1984) stated that in general life cycle of fish, there are three types of habitat *i.e.* reproduction, feeding and refuge in periods of unfavourable conditions. These habitats need not to be the same at different stage of life. Fishes will move among these habitats at the right time during their life cycle. In the broad sense, two major types of life cycle are recognized, holobiotic and amphibiotic. Holobiotic is a life cycle that fish spends the entire life in seawater or freshwater. Amphibiotic, however, is a life cycle that fish travels between different salinity environments. From a more practical point of view, three patterns of fish migration may be separated in terms of the biomes as:

Oceanodromy – migrations occurring entirely at sea;

Potamodromy – migrations occurring entirely in freshwater; and

Diadromy – migrations occurring between freshwater and marine environment.

Northcote (1984) provides a definition of migration as: *"those movements that result in an alternation between two or more separate habitats, occur with a regular periodicity within an individual's lifetime, involve a large proportion of the population and involve directed movement at some stages of the life cycle"*. For the oceanodromous and diadromous migrations, e.g. tunas and salmons, they are well studied because of the distinctive migratory route. In contrast, for some freshwater-resident fishes, the distance of migration is relatively short and unclear.

In riverine ecosystem, potamodromous is a typical migratory pattern that fish moving entirely within freshwater. Many freshwater fish species exhibit upstream spawning migration. Such migration may help to offset downstream drift or translocation of young life stages to some degree, or enhance their dispersal over a range of appropriate habitat (Northcote, 1984). Most riverine fishes involve migration within river systems or between river and lake. The migration takes place for several purposes such as spawning, feeding, and predation or pathogen or pollution avoidance (McKeown, 1984; Wootton, 1992). At the upper stretch of river, water is well oxygenated with a high current that preventing the settlement of silt, and lack of predators on eggs and larvae. Seasonal high water spills over the riverbank and surrounding area, becoming the large floodplain for feeding and spawning area (Wootton, 1992).

Amongst the purposes of migration, spawning migration is always the main concern of the potamodromous fish (Welcomme, 2001). During the spawning migratory period, adult fish develop their gonads. Many physiological activities make the gonad changes in structure and function. The significant performances are the maturation of gonad and the level of sex steroid hormones (Lambert *et al.*, 1991), which can be found in blood plasma and urine (Canario, 1991).

2. The Stimulus for Spawning Migration in Fish

The internal and external cues interact to stimulate a fish to migrate. This section outlines some of environmental factors which act as stimuli for the onset and maintenance of spawning migratory behaviour.

2.1 Internal Factors

Genetics: Lucas *et al.* (2001) stated that genetic basis is one of the signals for migratory behaviour in many freshwater fishes. Evidence of genetically based variations in life history and migratory behaviour of salmonids, three-spine stickleback and walleye has also been obtained, although life cycle characteristics in these species are also strongly influenced by environmental conditions.

Homing: Homing is the behaviour of adult fish that migrates back to spawning areas where it was born. Baggerman (1990) stated that the reproductive process often exhibits endogenous rhythms controlled by internal “biological clock”. It is an advantage behaviour that fish return to an environment known to be suitable for reproduction at a time when other sexually mature fish will also be presented (Wootton, 1992). It is evident, therefore, that the ability to come back home can be an important strategy in maintaining an individual’s genetic fitness. The ability to come back to a particular natal spawning location has been well documented for salmonid species (Lucas *et al*., 2001).

2.2 External Factors

Light: Photoperiod is known as the main environmental factor which influences the gonadal maturation in temperate fishes (Munro *et al.*, 1990; Redding and Patiño, 1993). The gonadal maturation also strongly influences by the variations of temperature, oxygen and other physicochemical variables. In tropical zone, on the other hand, photoperiod is mostly constant all year round and may have less effect to tropical fish compared to the lunar cycle (Lucas *et al.*, 2001). The moonlight can have a strong influence on the periodicity of upstream and downstream migrations. Moon phase also strongly influences diel vertical and horizontal migratory behaviour of fish in some lake systems (Lucas *et al.*, 2001). This circumstance coincides the upstream migration of many cyprinid fishes in the Lower Mekong Basin (Warren *et al.*, 1998).

Temperature: In many species, the periodicity of reproduction is intimately dependent on temperature. Increasing temperature was indirectly responsible for decreased dissolved oxygen concentrations in summer, which stimulated larvae to drift or actively swim from streams into lakes. For those species spawning during early spring in temperate zone, there are further constraints for starting a spawning migration at a very low temperature. In tropical zone, temperature may change slightly depend on the wet and dry season. Tropical species tend to have an extent spawning period, or continuous breeding throughout the year. Spawning peaks usually occurs associated with seasonal rainfall or flood (Lam, 1983; Lowe-McConnell, 1987). In contrast with a statement of Kramer (1978), the characoid species behave differently in the same tropical river systems, some species breed during wet season whereas others breed in dry season. Moreover, optimum range of temperature affects directly to yolk conversion efficiency and larval development (Gerking, 1980; Herzig and Winter, 1986).

Water quality: Balon (1975) suggested that the spatial and temporal variation in breeding success of fish depended on the optimum level of sufficient dissolved oxygen (DO). Other parameters of water quality, which related to reproduction, were turbidity, pH (Gerking, 1980; Daye and Glebe, 1984; Gunn and Weller, 1984), ammonia (Burkhalter and Kaya, 1977) and nitrate (Lewis and Morris, 1986).

3. Maturation Stage of Fish Ovary

In reproductive biological study, the fishery biologist mainly focuses on maturity stages of females i.e. changes of the ovaries. Since the success of offspring production is limited by egg production in a greater degree than sperm production (Helfman *et al.*, 1997). The maturity stages of fish ovary can be categorized into six stages as shown in Table 1. Significant changes comprise the increasing in gonadosomatic index (GSI) and enlarging of egg size.

Table 1 The maturity stages of fish ovary.

Stage	Description	Ovary	Eggs
1	Resting	Thread-like, translucent, small and undeveloped	None visible to naked eye
2	Developing	Meduim to large, cream/orange, opaque and almost filling body cavity	Oocyte visible and opaque
3	Ripe	Ovary full and almost filling body cavity	Hydrated oocyte visible, translucent, large and round
4	Ovulated	Ovary completely filling body cavity	Eggs in oviduct and can be extruded with gentle pressure
5	Spent	Ovary small, flaccid and bloody	Can be found some residual eggs

Applied from De Silva *et al.* (1985); Pankhurst and Carragher (1991); King (1995).

The ovaries of teleosts are different from most other higher vertebrates. All oogonia of females may not develop to be eggs by meiosis during early development. In the ovarian tissue, resting and proliferating oogonia can be found in the interstices between larger ovarian follicles in the gonads of most adult female teleosts (Takashima and Hibiya, 1995).

The maturation stage of fish ovary can be examined by histological study. There are many criteria to divide the stages of ovarian development. Ovaries can be also examined for the presence of follicular atresia. Atretic follicles are classified according to the criteria as described in Table 3 (Johnson *et al*., 1991).

Table 2 Classification for ovarian development stages, based on histological criteria.

Stage	Features
Regressed	Primary oocytes or a mixture of primary and secondary oocytes present; secondary oocytes may be beginning to enlarge but are not vacuolated
Previtellogenic	Oocytes with clear peripheral vacuoles (cortical alveoli); zona radiata present
Vitellogenic	Yolked oocytes present
Spawning	Yolk globules blending, hydrated oocytes present; postovulatory follicles visible
Spawned out	Many postovulatory follicles present; yolked oocytes undergoing resorbtion; inflammatory infiltrate, beta or gamma atretic follicles and/or macrophage aggregates generally present

Table 3 Classification for stages of follicular artesia, based on histological criteria.

Stage	Features
Alpha atresia, yolked oocytes	During this phase, oocytes are being resorbed, leaving only follicular cells. Nucleus and yolk globules disintegrate, zona radiate dissolves, and granulosa cells enlarge and invade disintegrating oocyte, absorbing both yolk and basophilic cytoplasm. Process is complete when all yolk and basophilic cytoplasm are gone
Alpha atresia, non-yolked oocytes	Similar to alpha atresia of yolked oocytes, except that no yolk, only basophilic cytoplasm, is present
Beta atresia	Atretic follicle appears as a compact structure composed of numerous disorganized granulose cells surround by a thin thecal and blood vessel layer
Gamma atresia	Atretic follicle is smaller than a beta follicle and contains light-yellowish flocculent material. Nuclei are irregularly shaped, and follicle is still surrounded by a thecal and blood vessel layer
Delta atresia	Follicles are small structures composed of 2-20 granulosa cells in ovarian connective tissue. Follicles are not surrounded by thecal cells or blood vessels, and granulose cells contain dark-yellow finely granulated pigment

Based upon the dynamics of the ovarian development and differentiation, Murua and Saborido-Ray (2003) defined three types of ovarian development that closely related to fish spawning pattern as follow:

3.1 Synchronous: All the oocytes develop and ovulate at the same time. Such ovaries are found in teleosts that spawn once and then die such as, anadromous *Oncorhynchus* species and catadromous eels. The oocyte diameter frequency distribution is represented by a single belled-shape. The females which their ovaries are synchronous are termed "synchronous ovualtors" and also known as "total spawner".

3.2 Group-synchronous: There are at least two stages of oocytes can be recognized in the same ovary at the same time. Each stage usually calls as a "clutch". The larger oocytes, or the latest stage, are released first and the smaller oocytes from other clutch(es) are recruited. The former oocytes usually spawn during the current breeding season, while the latter oocytes will spawn in the next breeding season. These species are also called "partial spawner".

3.3 Asynchronous: All stages of oocytes can be found randomly mixture in the same ovary without any dominant stages. Fishes which are termed "asynchronous ovulators", eggs are recruited and ovulated from the population of yolked oocytes is several batches during each spawning season or all year round spawn. These species are also called "batch spawner". Batch spawning can be seen as a strategy that fish releases eggs over a long period of time to increase the survival probability of offspring (Lambert and Ware, 1984).

4. Fish Gonadal Hormones and their Functions

Gonadal hormones in fish are synthesized from many parts of the body but mainly from testes and ovaries. Most of gonadal hormones are steroid molecules which regulate diverse functions including gametogenesis in the gonads, secretory activity of the hypothalamus and pituitary, the expression of various secondary sex characteristics and behaviours, and general metabolism. Steroid hormones play various roles in both immature and mature fish. In immature stages, steroids probably regulate in the differentiation of the gonads and other sexually dimorphic tissues. In mature stages, gametogenesis and spawning in both sexes are directly controlled by steroids hormones on germ cells or indirectly on somatic elements of the gonads. Moreover, sex steroid hormones also regulate in many reproduction-linked behaviours *i.e.* development and recognition of secondary sexual characteristics, pheromonal attraction, spawning, and parental care. Other important non-steroid hormone which is well-studied is 'prostaglandins', a family of cyclopentane fatty acids found in most tissues. Many papers support its activity as a stimulator for the ovulation in female fish (Redding and Patiño, 1993).

4.1 Ovarian Hormones

In the ovary, the primary sites for steroid synthesis, Gonadotropin (GtH-I and GtH-II), are the theca and granulosa cells of the ovarian follicle.

4.1.1 Vitellogenesis: Oocyte of non-mammalian vertebrate grows in the first meiotic prophase. The principal events responsible for the enormous growth of fish oocytes occur predominantly during the phase of development termed vitellogenesis (Nagahama, 1994). In many teleosts, GtH-I stimulate testosterone biosynthesis in theca cells and diffuse into the granulosa cell layer. Testosterone is converted to 17 β-œstradiol by aromatase process. Estrogen, 17 β-œstradiol (Figure 3 (A)) is released into the vascular system and stimulates the hepatic synthesis of the glycolipophosphoprotein egg yolk precursor: vitellogenin (VTG). VTG then passes through the granulosa and theca cell layers, and binds to specific receptor-mediated endicytosis (Janz, 2000). The uptake of VTG, through low-affinity/high-capacity binding sites on the plasma membrane of the oocytes is stimulated by GtH-I. In carp, *Cyprinus carpio*, a parallel two-cell-type mechanism operates toward final oocyte maturation: theca cell produces 17α-hydroxyprogesterone (17-OH-P) which diffuses into the granulosa cells to be converted to 17α, 20β-dihydroxy-4-pregnen-3-one (17, 20-P) (Figure 3 (C)). Nevertheless, this model can not be applied to all teleosts (Yaron, 1995).

4.1.2 Oocyte maturation: After vitellogenesis, oocytes enlarge for preparing maturation and ovulation. The primary mediators of oocyte growth and maturation in fishes, GtHs, are the same as in higher vertebrates. In maturation stages, 17α-hydroxyprogesterone (17α-P) is produced in theca cells by being stimulated from GtH. 17α-P diffuses into the granulosa cells and provides the substrate for synthesis 17, 20-P, which is catalyzed by 20β-hydroxysteroid dehydrogenase (20β-HSD) (Nagahama, 1994). 17α, 20β-P is identified as the endogenous maturation inducing hormone (MIH) in most fishes including salmonids, killifish, medaka, and a number of catfishes (Janz, 2000).

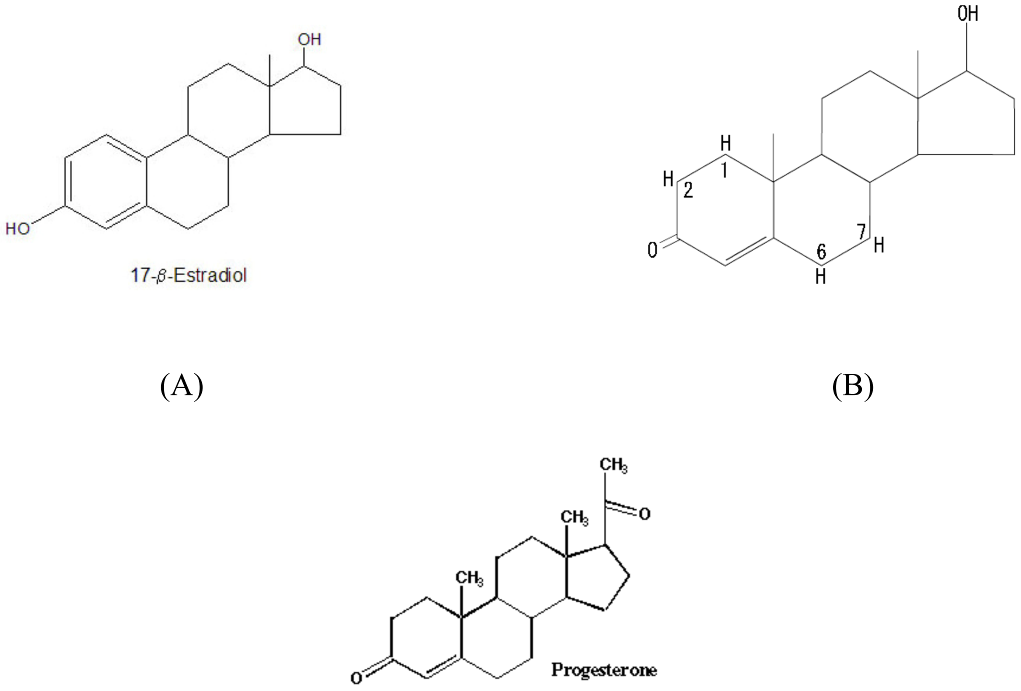
4.1.3 Ovulation: Ovulation involves the formation of prostaglandins and the synthesis of proteases for degrading follicular wall. After the wall ruptures, eggs emerge freely and release outside. Contractility of the follicular wall may take part in the process of ovulation (Yaron, 1995).

Sexual maturation is examined by the magnitude of sex steroid hormones in plasma. In immature females, plasma sex steroid levels are very low (< 0.3 ng/mL). Although the main circulating sex steroid hormone in female fishes is 17 β-œstradiol, significant levels of testosterone are also present since it is the immediate precursor in 17 β-œstradiol (Janz, 2000). In addition, plasma levels of 17β-œstradiol and vitellogenesis are positively correlated and increased in parallel (Nagahama, 1994). Plasma œstradiol increases sharply at the beginning of vitellogenesis, and then declining after spawning. It then, returns to baseline levels by the time spawning is completed (Johnson *et al.*, 1991). Lou *et al.* (1984) studied the endocrine profiles in the females of twice-annually spawning strain of rainbow trout, *Salmo gairdneri*. In the fish that were successful ovulators in the summer, plasma 17β-œstradiol rapidly increased in January, attaining the highest values from March to May and then decreased before ovulation. Plasma GtH gradually increased from January followed by a second increased just before ovulation in summer. In the fish that failed to mature in summer, plasma œstradiol and GtH showed little increase from January to February, and synchronously decreased in March. Prolong daylength in spring probably inhibited GtH secretion in the once-spawners, but not in the twice-spawners which already had high plasma œstradiol and GtH at the critical period between late February and late March.

4.2 Testicular Hormones

In contrast with ovarian hormones, little is known regarding testicular hormone regulation in fishes. Testicular morphology is diverses among fishes. Pituitary GtHs stimulate the testicular synthesis of a variety of steroids in teleosts such as testosterone (Figure 3 (B)), 11-ketotestosterone (11-KT) and androstenedione. 11-KT presents in many teleosts and may represent the piscine homolog of the potent circulating mammalian androgen i.e. 5α-dihydrotestosterone (Janz, 2000). The GtH regulation of spermatogenesis and spermiogenesis is apparently mediated by 11-KT, which is secreted by Leydig cells. However, the acquisition of sperm motility requires the stimulation of the sperm duct by GtH, or by 17, 20-P which is produced by spermatozoa from 17α-hydroxyprogesterone (17-OH-P) (Yaron, 1995).

Similar to females, circulating levels of sex steroids in immature male fishes are very low. The main circulating androgens in teleosts, 11-KT and testosterone, can be determined in matured fish (Janz, 2000).



(A)

(B)

(C)

Figure 3 Structural formulas of fish sex steroid hormones
(A) 17 β-estradiol, (B) testosterone and
(C) 17α, 20β-dihydroxy-4-pregnen-3-one
Source: Scott and Canario, 1987

5. The Mekong River

The Mekong River (Figure 4) is known as ‘a mother of all waters’ or ‘the lifeblood of Southeast Asia’. It is the longest river in Southeastern Asia and the 12th longest river in the world. The river flows from the headwater on the Tibetan Plateau to the South China Sea with a distance of 4,800 km and has a catchment area covers 795,000 km^2. The upper part of the river is called Lancang Jiang (in China) for about 2,400 km and is characterized by deep gorges and steep declines. It passes the Golden Triangle, where are the borders of Lao PDR, Myanmar and Thailand. This is the starting point of Lower Mekong Basin (LMB) and the river runs for another 2,400 km to the sea. For a stretch of about 90 km it forms the common border of the Lao PDR and Thailand. There is an inland delta at the geological fault line forming also the 21m high Khone Falls on the Lao-Cambodian border. At Kratie about 545 km from the sea it becomes a lowland river. Then at Phnom Penh some 330 km from the sea, it is joined by Tole Sap River, which connects the Great Lake of Cambodia with the Mekong. There, the river splits into the Mekong proper and the much smaller Bassac to form a large estuarine delta, called the Nine Dragons in Viet Nam, before it empties in the South China Sea (van Zalinge, *et al.*, 2004))

Over 60 million people along the Mekong River and tributaries use the river for food source, water supply, transportation and many aspects of their daily lives. Its annual flood-drought cycles are important for sustainable production of rice, vegetable and fisheries (http://www.thewaterpage.com, 14 Oct 2005).

Figure 4 The Mekong River
Source: http://www.thewaterpage.com, 14 Oct. 2005.

5.1 Important fish habitats in the Mekong River

5.1.1 Floodplain: A floodplain is an area created by the monsoon annually. It is a “fish production sites” of the Mekong because of rich nutrients, foods and shelters. Fishes in the Mekong usually use floodplain at least certain parts of their early life cycle. Floodplain is also used as the main spawning ground for many riverine species. Such habitat has a suitable condition for early development of fish (Lowe-McConnell, 1987; Hoggarth *et al.*, 1999). The migration behaviours of fishes are adapted to the flood-pulse, and in different ways. In general, most species spend the dry season in refuge habitats. When the rainy season starts, the flood water increases the floodplain area and also conducts a lot of nutrients from the land into the floodplain. It is an ecological trigger for both spawning and migration behaviours. Spawning at the right time and place will enable offspring to enter floodplain habitats, where they can feed. Some species spawn on the floodplain itself, whereas others migrate upstream to spawn within the river channel and then rely on the river current to bring the offspring to the downstream rearing habitats. In addition, many larger juveniles and adult fishes actively migrate from dry-season shelters to the floodplains to feed (MRC, 2002).

5.1.2 Dry season refuge habitats: When the dry season comes, fishes have to move out from the floodplain according to the reduction of water level. They return to their dry season refuges. Generally, there are two types of refuge habitats in the Mekong River as:

a Permanent floodplain lakes and swamps

The ‘black fishes’ (see the 6th topic) mainly use floodplain lakes whereas ‘white fishes’ (see the 6th topic) mainly use river channels refuges (MRC, 2002).

b River channels

Deep areas in the river or ‘deep pool’ are particularly important as dry season refuges. In the Mekong River, certain stretches emerge as important locations for deep pools (MRC, 2002).

5.1.3 Spawning habitats for migratory fishes: Spawning habitats of Mekong fishes are generally believed to associate with

a Rapids and pools of the Mekong mainstream and tributaries

Rapids are used as spawning habitats by most of the large species of Pangasiids and Cyprinids.

b Floodplains

Floodplains are used as spawning habitats, mainly black fishes. Other species may spawn in river channels in the open-water column and rely on particular hydrological conditions to distribute offspring (eggs and/or larvae) to downstream rearing habitats.

Nevertheless, information on spawning habitats for migratory species in the river channels of the Mekong Basin is little known. Information about spawning can be obtained by indirect methods such as observations of ripe eggs in fishes. For fishes that spawn in main river channels, spawning is believed to occur in stretches where there are many rapids and deep pools, e.g. (1) Kratie-Khone Falls stretch; (2) the Khone Falls to Khammouan/Nakhon Phanom stretch; and (3) from the mouth of the Loei River to Bokeo/Chiang Khong. (MRC, 2002).

Uniquely, in the Mekong River Basin, rapid is recognised as one of the main spawning site for the Mekong indigenous species such as Jullien's golden-Price, *Probarbus julienni* Sauvage (Viravong, 1996) and *Luciocyprinus striolatus* (Warren, 1999).

6. Fish Migration in the Mekong River

In the Mekong River basin, there are three distinct types of migration system depended on geographic areas namely lower (LMS), middle (MMS) and upper Mekong migration system (UMS). These migration systems, however, have inter-connected. The Mun River itself is a part of MMS that has a general qualification as described in Table 4. The riparian fishermen can remind the anecdotal information of the migration patterns of such species along the middle and lower Mekong mainstream. Almost all-indigenous species perform both longitudinal and lateral migration purposes but the major cause is to spawn (Poulsen and J⌀rgensen, 2001).

The special terminations of fishes in the river system are 'black' and 'white' fish (Welcomme, 1985). Black fishes are species able to survive in swamps and other water bodies on the floodplain through the dry season, with only limited, lateral migrations. These fish often have adaptations that allow them to endure adverse conditions on the floodplain, such as low DO. The group consists mainly of carnivores and detritivores such as Family Channidae, Clariidae, Bagridae and Anabantidae (Mattson and Jutagate, 2005).

White fishes, on the other hand, are fishes that depend on habitats within the main river channels for the main part of the year. Most of them venture into flooded area during the monsoon season then return to their river habitats at the end of the flood season (Welcomme, 1985). Important representatives of this group are many species of family Cyprinidae, Balitoridae, Cobitidae, Pangasidae and Siluridae (Mattson and Jutagate, 2005).

There is another group of fishes that is classified between black and white fishes: 'grey fishes' (Welcomme, 2001). Grey fishes are short migrations species that moves between floodplains and adjacent rivers and/or between permanent and seasonal water bodies within the floodplain.

Table 4 The Middle Mekong Migration System (MMS)

General ecological attributes	Mekong-specific ecological attributes
Dry season refuge habitats:	Deep pool stretches, both in the Mekong mainstream and within major tributaries. The important stretch is the Khone Falls throughout Kammouan/Nakhon Phanom. Deep pools downstream from the Khone Falls also are linked to the MMS and the LMS.
Flood-season feeding and rearing habitats:	Floodplains of this system are mainly associated with major tributaries (e.g. the Mun/Chi System, Songkhram River, Xe Bang Fai River, Hinboun River).
Spawning habitats:	Rapids and deep pool systems in the Mekong mainstream, river channels and floodplain habitats associated with tributaries.
Migration routes:	Connect between the Mekong River (dry season habitats) and major tributaries (flood season habitats).

Source: Applied from MRC (2002)

7. Fisheries in the Lower Mekong Basin

The Mekong River has a single annual flood pulse that peaks in August to October, depending on area, which leads to the inundation of a floodplain for about 70,000 km^2 (van Zalinge, *et al.*, 2004). There is a strong relationship between the intensity flooding and fisheries production. The flood pulse is also generates and maintains the diversity of physical habitats, which in turn is necessary for the maintenance of biological diversity. Any reduction in the complexity of the ecosystem is likely to have repercussion on diversity and productivity (Mattson and Jutagate, 2005).

Fishing has evolved over many centuries and a great diversity of traditional gear is in use. In Cambodia alone, more than 150 gear has been identified (van Zalinge *et al.*, 2004). Although there are some large-scale fishing operation in Cambodia and Viet Nam, but the majority of the fisheries are small-scale. The small-scale fisheries are increasing according to the modern fishing gear, particularly mono-filament gillnets. The environment of LMB is generally healthy but the average size of fish caught is getting smaller and several of the large species i.e. the Mekong Giant Catfish (*Pangasianodon gigas*) are threatened (Mattson and Jutagate, 2005).

The estimation of fishery yield from LMB water bodies is presented in Table 5. The productivity is quite variable but high in general.

Table 5 Fishery yield from water bodies in the LMB.

Water body	Yield (kg/ha/yr)
Great Lake, Cambodia	205
Floodplain fishery, Phnom Penh, Cambodia	375
Nam Ngum Reservoir, Lao PDR (47,500 ha)	144
Sirindhorn Reservoir, Thailand (21,000 ha)	222
Reservoirs, Thailand	83
Small, communal water bodies, NE Thailand	26-2,881 (median 652)
Rice fields, LMB	25-300
Rice-fish culture, Viet Nam	370
Rice-fish culture, Lao PDR	120
Pond culture, LMB	4,800

Applied from Mattson and Jutagate (2005).

8. The Mun River

The Mun River is the longest river in the northeastern region of Thailand, originated in the Eajarn Mountain in Nakorn Ratchasima Province. The confluence of Mun River to the Mekong is Pak Mun, Khong Jiem District, Ubon Ratchathani Province. The total distance from the origin to the confluence to Mekong is 641 km with the 117,000-km^2 catchment area and the average annual water flow is 24,000 m^3 (Duangswasdi and Chookajorn, 1991) (Figure 5). The special characteristic of this river in the near Mekong confluence region is large and has a number of rapids including trenches (deep up to 6 m) (Krudpan, 2001). The Mun river system is known as one of the productive river system in the Lower Mekong Basin. Amornsakchai *et al.* (2000) reported that 265 fish species were recorded in the Mun-Chi watershed before 1994 and about 10 were introduced species. Fish species diversity in the Mun River, especially in Ubon Ratchathani Province, has fluctuated from time to time: 115 (Thaentong and Siripan, 1969), 75 (Team Consulting Engineers, 1982), 68 (Doungsawasdi and Chookajorn, 1991), 70 (Doungsawasdi and Doungsawasdi, 1992), and 152 (Schouten *et al.*, 2000) species.

In the Mun River, floodplain habitats are mainly associated with its tributaries. Fishes migrate seasonally from mainstream dry season habitats to floodplain feeding/rearing habitats in these floodplain areas. At the onset of the flood season, fishes generally move upstream within the Mekong mainstream until they reach the mouth of tributary. The strong current, from rapids area, induces fishes to move upward into the Mun River. They swim further upstream until they can move into floodplains. Then they move backward through the tributary river and, eventually, to the Mekong mainstream, where many fishes spend the dry season in deep pools. This is a very simplistic description of the main movements, and there are considerable variations in the general pattern, both between different species and within species (MRC, 2002).

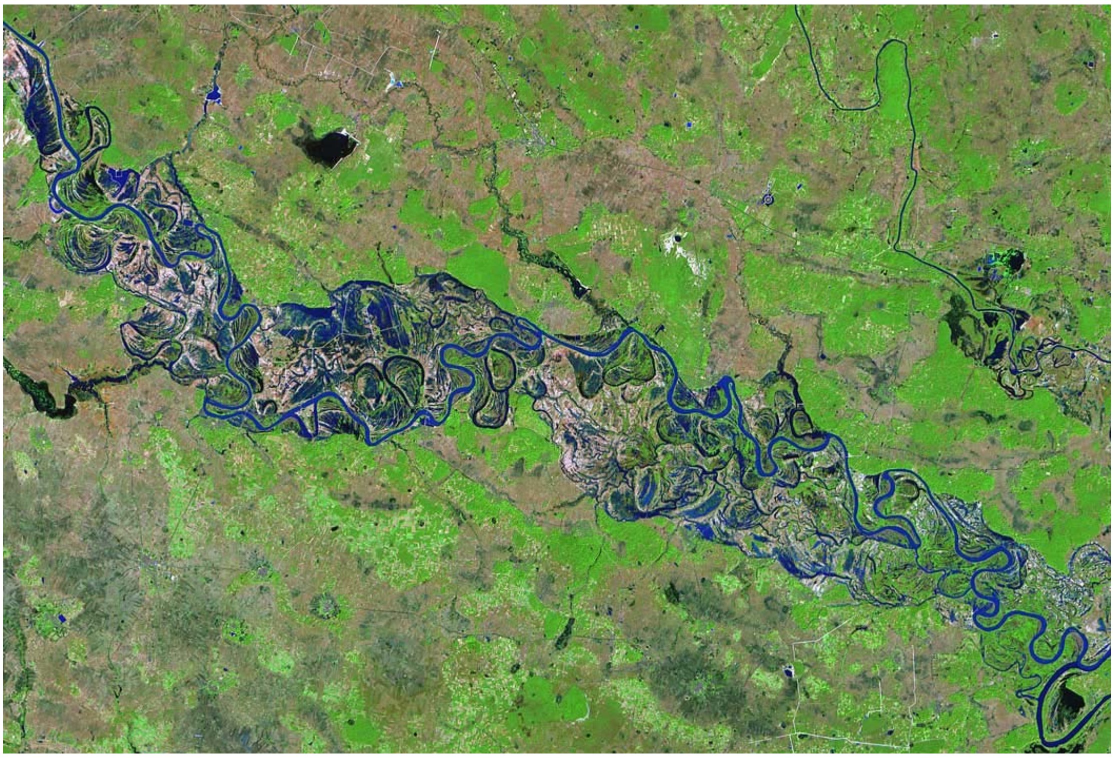


Figure 5 The Mun River
Source: http://www.geocities.com/satelthai/resources/galleries/, 1 March 2006.

Assessment of species, catch and standing stock of fisheries resources in the Mun River, before the dam was constructed were studied (Doungsawasdi *et al*., 1993; Thaenthong and Siripan, 1969; EGAT, 1982; Doungsawasdi and Doungsawasdi, 1992.; Polprasit, *et al*., 1997a, 1997b). They assessed catch and standing stock of fish compared between wet and dry season and found the catch and standing stock in wet season was lesser than dry season. Amornsakchai *et al.* (2000) suggested that when rivers change to stagnant water, loss of fish productivity occurred especially in the migratory and rapids dependent species. Even though some migratory species are able to establish populations in storage reservoirs, Pangasiids and Silurids are unable to establish populations in Thai storage reservoir. It depends on fish behaviour especially spawning ground selection. Most Pangasiids and Silurids usually spawn in the rapid with run through current (Viravong *et al*., 2005).

Amornsakchai *et al.*(2000) reported that fish species in the Mun river decreased drastically from 256 to 96 after the Pak Mun Dam was constructed. The calculated loss of 169 fish species was exacerbated by the difference in efforts and number of sampling points of the fish surveys before and after dam construction. Species composition changed in all of the areas. The fish survey showed the decline of catch in many fish species considerably in the upstream of the dam because of fishes inhabit downstream area more than upstream area. Fishing gears which specifically designed for catch of Pangasiidae that migrating from the Mekong into the Mun River i.e. Dtoom trap, has been completely unable to operate upstream of the dam.

Jutagate *et al.* (2001) investigated fish species diversity and ichthyomass after five years impoundment of the Pak Mun Dam. Fifty-nine (59) fish species were found. Limnophiles such as barbs (*Barbodes* sp., *Hampala* sp. and *Rasbora* sp.), snakeheads (*Channa* sp.) and gobies (*Oxyeleotris* sp. and *Tridentiger* sp.) were the dominant species. Rheophilic species, on the other hand, were not commonly found and the samples were in small size. They also reported shark catfish in the catch composition. Numbers of the rheophilic species increased following to the distance of upstream. The ichthyomass was about 5 kg ha^{-1}. The water qualities, especially DO, were lower than the standard criteria. The benthic fauna which is bio-indicator of polluted condition was found in this study.

Since changes in river flow and ecosystem, this led to the impacts on the livelihood of the people in that area, the Assembly of the Poor protested the Government to solve their problems. In 2001, the Government then ordered EGAT to open all the sluice gates for one year (June 2001- May 2002) and asked UBU to set the task force to study and find out the migration measures. In terms of fish diversity, 184 fish species from 44 families were captured. Thirty-four (34) species were Mekong endemic species and 11 were introduced species. Moreover, 48 species were 'uncommon species' since local fishermen have not seen in these areas for a long time. Most catches were from five families' *viz.* Cyprinidae, Pangasiidae, Bagridae, Siluridae and Cobitidae. The catch was also included two common stocking fishes: carp, *Cyprinus carpio* (Linn.) and Nile tilapia, *Oreochromis niloticus* (Linn.) as well as a stocking shellfish and giant freshwater shrimp, *Macrobrachium rosenbergii* (de Man) (Jutagate, *et al.*, 2005).

The latest report on fish species diversity in the Mun River was studied by Chaengkit *et al.* (2004). The survey was conducted during May and November 2001 and February 2002. They found 90 fish species from 26 families, including shark catfish, in the Mun River which started from Nakhon Ratchasima, Burirum, Surin, Sri Saket through Ubon Ratchathani (Warin Chamrab District). The dominant group from the sample was Cyprinids which was found 43 species.

9. Pak Mun Dam and its Impact on Fisheries Resource in the Mun River

9.1 General information

The Pak Mun Dam was built on the Mun River, 5.5-km upstream from its confluence with the Mekong, in the province of Ubon Ratchathani, northeastern Thailand (Figure 6). The type of the dam is roller compacted concrete with a maximum height of 17 m and total length of 300 m. The reservoir has a surface area of 60 km^2 at normal high water level of 108 metres above the mean sea level (MSL) and a capacity of 225 million m^3.The dam *per se* is a run-of-the-river hydropower plant. Its operating rules are designed to ensure that the water level will not rise above 106 m MSL during the dry season, from January to May and retain a maximum level of 108 m MSL for the rest of the year (Amornsakchai *et al.*, 2000).

Figure 6 The Pak Mun Dam

9.2 Benefits and impacts of Pak Mun reservoir in fisheries

Only seven percent of the project benefits were attributed to fisheries (EGAT, 1988). The environmental impact assessment (EIA) predicted that fish production from the reservoir would considerably increase. But some fish species may be affected by the blockage of river flows by the dam. The fish yield, expected from the 60 km^2 reservoir area, was 100 kg ha^{-1} yr^{-1} without fish stocking and 220 kg ha^{-1} yr^{-1} with the fish-stocking programme (Team Consulting Engineers, 1982). Run-of-the-river reservoirs, on the other hand, cannot sustain such high yields, as they do not provide the appropriate habitat for pelagic fish species. In Thailand even the storage reservoirs that perform better under fish stocking programmes have a fish yield of about 19 to 38 kg ha^{-1} yr^{-1}(Jutagate *et al*., 2001). The predicted fish yield from Pak Mun head pond was too high. A more realistic estimate would have been around 10 kg ha^{-1} yr^{-1}. There has been no evidence to indicate that the fish productivity of Pak Mun reservoir has reached anywhere near the anticipated 100 kg ha^{-1} yr^{-1} (Jutagate *et al*., 2001).

Location of the dam on the Mun River has affected several migrating and rapids dependent species. Therefore, the fishpass was constructed to help the upstream migration of the fishes (Figure 7). Amornsakchai *et al.* (2000) reported that, in the Mun River, 77 species were migratory and 35 species where dependent on habitat associated with rapids, which were inundated after the impoundment. Pholprasit *et al.* (1997 a and b) reported the total 63 fish species (15 families) moved across the fishpass to the upstream area and claimed that more than 50 % of the fish species in the Mekong and Mun River utilised the fishpass. Schouten *et al.* (2000) denoted that at least 50 fish species disappeared after the dam was constructed. Schouten *et al* (2000) and Amornsakchai *et al.* (2000) argued that the pool and weir type fishpass, at Pak Mun Dam, was not well performed in terms of allowing the fishes to move upstream. They suggested that a vertical slot fishpass or a Denil type might have been more effective.

Figure 7 Fishpass at Pak Mun Dam
Source: http://www.GuideUbon.com, 1 March 2006.

The magnitude of CPUE, ranged from 0.38 to 1.70 kg fishermen^{-1} night^{-1} at downstream area and 0.61 to 2.71 kg fishermen^{-1} night^{-1} at upstream area. There were not statistical differences among each month CPUE in both areas whereas the monthly %IRI of the fish species caught varied between months (Jutagate *et al.*, 2005).

10. Biology of Shark Catfish

Shark catfish or “Pla sa wai noo” is a scaleless freshwater fish found in the Southeast Asian waters: Mekong and Chao Phraya basins and also from Sumatra, Indonesia (Rainboth, 1996). The classification of this species is described as followed (Roberts and Vidthayanon, 1991):

Phylum Chordata
  Class Actinopterygii
    Order Siluriformes
      Family Pangasiidae
        Genus Helicophagus
          Species waandersii

Helicophagus waandersii Bleeker, 1858 (Figure 2).

There are three species of genus *Helicophagus* namely: *H. waandersii* Bleeker, 1858, *H. typus* Bleeker, 1858 (Roberts and Vidthayanon, 1991), and *H. leptorhynchus* Ng and Kottelat, 2000 (Ng and Kottelat, 2000). All helicophagids are closely related to pangasiids. The distinguishable point of difference among them is teeth. Helicophagids have vomerine teeth, which are two small oblique widely separated patches, but lack of palatine teeth whereas pangasiids have both vomerine and palatine teeth (Smith, 1945; Rainboth, 1996).

Ng and Kottelat (2000) described a new species of helicophagid; *H. leptorhynchus*. They sampled the fish from Indochina: the Mun River, Nakhon Phanom and Mukdahan where all located in northeastern Thailand, Bangpakong River (central Thailand), and the Mekong River (Lao PDR, Vietnam, and Cambodia). The morphology of *H. leptorhynchus* is very similar to shark catfish. It has been previously identified as *H. waandersii*. Actually, *H. leptorhynchus* has a longer fin (34.5-38.2% SL vs. 31.9-34.3% SL), shorter caudal peduncle (12.9-15.3 % SL vs. 15.6-16.7% SL), and longer head (20.8-22.8% SL vs. 14.1-15.9% SL) than shark catfish. Its snout always slender than shark catfish when views laterally.

The body of shark catfish is sub-elongate. It has two dorsal spines, seven dorsal soft rays, 37-40 anal soft rays, six pelvic soft rays, and one adipose fin (Smith, 1945; Taki, 1974; Rainboth, 1996). It has two pairs of barbels, a maxillary pair and a mandibular pair. Maxillary barbel extends beyond base of pectoral fin. Mandibulary barbel, however, reaches at the base of pectoral fin. The anterior nostrils, which are directed forward or upward, pierce the front border of snout while the posterior nostrils locate midway between anterior ones and eyes (Smith, 1945).

The position of mouth is sub-terminal or inferior (Taki, 1974) that makes the fish commonly lives in demersal environment (Roberts and Vidthayanon, 1991). The feeding behaviour of shark catfish is molluscivore both univalve (Smith, 1945) and bivalves (Roberts and Vidthayanon, 1991). It is note that another two species of *Helicophagus* also feed in bivalves. *H. typus* entirely feeds on bivalves, *Potamocorbula* sp. (Corbutidae) (Musikasinthorn *et al.*, 1998) while *H. leptorhynchus* feed predominantly on bivalves, *Corbicula* sp. (Corbutidae) and *Physunio* sp. (Amblemidae) (Ng and Kottelat, 2000). A study on stomach content of shark catfish in the lower Songkhram River basin showed that 76 percent of occurrence is mollusk, 22 percent is aquatic earthworm and two percent is detritus (Boonyaratpalin *et al.*, 2002).

Spawning season of shark catfish in the Mekong River basin depends on locality. Most of the spawning occurs once a year. In the Mekong main stream, the spawning season begins from March to July, mainly in May through June, based on the presence of eggs in abdomen of the female. In Don Thap Province (Lao PDR.), shark catfish spawns throughout the year because of the presence of fry all year round (Chan *et al.*, 1999). In Hoo Som Yai, Champasak, spawning season probably occurs in September to October (Singhanouvong *et al.*, 1996a). In the Mun River, shark catfish has a spawning activity at the beginning of the rainy season until the end of August or the early of September (Amornsakchai *et al.*, 2000).

There are only two empirical models describing biological parameters of shark catfish. First, the length-weight relationship, which analysed by Singhanouvong *et al.* (1996a), is $W = 0.0008TL^{3.549}$ where W is weight (g) and TL is total length (cm). The fish was sampled from Mekong River at Hoo Som Yai, Champassack Province in Lao PDR. Fish length ranged from 23.7 to 45.0 cm. Second, length-length relationships, which retrieved from Froese and Pauly (2004), is: $TL=1.168SL$, where SL is standard length (cm).

Shark catfish is one of the commercial native species in the Mekong River basin. People consume it both in fresh and salty grilled style. The yield of shark catfish is from riparian fisheries only because it cannot be presently cultured. The standard fishing gears are seines, gillnets, cast-nets and traps (Rainboth, 1996; Khoa and Huong, 1993; Singhanouvong *et al.*, 1996a). In the lower Songkhram River basin, shark catfish can be caught by beach seine and stationary trawl net in the main river, and barrage fisheries in floodplain area (Boonyaratpalin *et al.*, 2002).

11. Distribution of Shark Catfish

Shark catfish is commonly found as a native species in the Southeast Asian waters. It is distributed in Mekong and Chao Phraya basins and also from Sumatra, Indonesia (Rainboth, 1996).

11.1 Indonesia: A little is known from Palembang, Sumatra (Suvatti,1981) (Figure 8).

11.2 Chao Phraya River basin: Shark catfish formerly is a common species in Bangkam River, Lopburi and Chao Chet River which both are branches of the Chao Phraya River. It was also caught in the Gulf of Thailand far off the mouth of Chao Phraya River at the time that the pouring out of large rivers in Central Thailand reduced the salinity of the upper gulf (Smith, 1945). Moreover, shark catfish was also found in many parts of Chao Phraya River basin e.g. Sirikit Reservoir (Uttaradit Province), Nakhon Sawan, Chai Nat and Ayutthaya Province (Sidthimunka, 1970; Mongkolprasit *et al.*, 1997; Vidthayanon *et al.*, 1997) (Figure 9).

Figure 8 Distribution of shark catfish in Sumatra, Indonesia
Source: Modified from http://traveling.igw.dk/indonesia_1995_1.htm

11.3 Mekong River basin:

Viet Nam: Shark catfish is found in Mekong Delta (Khao and Houng, 1993) and also in two rivers viz. Tien River and Hau River. (Thuong *et al.*, n.d.).

Cambodia: Kottelat (1985); Roberts and Vidthayanon (1991); Rainboth (1996) reported shark catfish in Tonle Sap and Phnom Penh but Lim *et al.* (1999). Lim *et al.* (1999) suggested the difference in results could come from different sampling methods. The previous study of Lagler (1976); Penh (1996) (Lim *et al.*, 1999), and Rainboth (1996) used research sampling whereas the study of Lim *et al.* (1999) used commercial data from professional fishing lot caught by fence, capture/killing room and seining during the year 1995 to 1997. Lim *et al.* (1999) concluded that, fish biodiversity was reduced from the past 40 years study by overfishing and modification of floodplain by deforestation. Formerly, shark catfish used to be caught in the Mekong fishing lot upstream of Phnom Penh. But nowadays, this fish becomes less contribution in catches (Puy Lim, *pers. com.*).

Lao PDR.: Shark catfish is a commercial species in Lao PDR. It was found in Tha Ngon, Tha Bo, Hatsalao (Taki, 1974), and Ban Hang Khon, 3-km below the fall line of the great waterfall of the Mekong basin at Lee Pee (Roberts, 1993). It is the most abundant catch at Don Khong above Lee Pee waterfalls. Shark catfish can be caught all year round but particularly abundant at the end of the year that the Don Khong fishermen said (Roberts and Warren, 1994).

Figure 9 Distribution of shark catfish in Thailand
Source: Modified from http://www.shunya.net/Pictures/Thailand/ThailandMap.gif

Northeastern Thailand: The distribution of shark catfish covers Nong Khai Province which is a part of the upper Mekong River basin, and the Mun River (Ubon Ratchathani Province) which is a part of the middle Mekong River basin (Mongkolprasit *et al*., 1997). Except for the dry season, shark catfish can be found in the river and floodplain area in the lower Songkhram River Basin (Boonyaratpalin *et al*., 2002). The composition of shark catfish in the Songkhram River which caught by beach seine, stationary trawl net and barrage of shark catfish was 1.25 percent by number and 2.67 percent by weight. In the Mun River, shark catfish can be found both upstream and downstream area far off Pak Mun Dam (Jutagate *et al*., 2005).

12. Migration Behaviour of Shark Catfish

Shark catfish is commonly found in medium to large-sized rivers (Taki, 1978). It migrates upstream when water level begins to rise at the beginning of the flood season and move downstream when water clears at the end of the flood season (Rainboth, 1996). There are two oppose statements about the movement of shark catfish; Rainboth (1996) stated that shark catfish lives permanently in river channels and does not move into flooded forests whereas Roberts (1993) mentioned that it enters to the flooded forest.

In the Mekong mainstream, shark catfish distributes from Mekong delta to Bokeo in northern Lao PDR. Along the Mekong River, Khone Falls are important barrier for all migratory species. Migration patterns above and below Khone Falls are significantly different. Below Khone Falls, shark catfish migrates upstream from October to February, and migrates downstream from May to July at least from Sambor to Muk Kompol Province of Cambodia. Shark catfish was reported to be a common species along the stretch and there were reports on its occurrence in the delta area. The migratory route started from Sambor to Khone Falls as well as in Mekong delta. Above Khone Falls, shark catfish seems to have two upstream movements. Firstly, during the late dry season from March to May that mainly along the stretch from Paksan to Loei. Secondly, during the early rainy season from May to August (Poulsen and Jørgensen, 2001) (Figure 10). In southern Lao PDR. Singhanouvong *et al*. (1996b) reported that shark catfish migrates upstream during the dry season in December to February.

In the Mun River, after Pak Mun Dam was completed, some migratory species are unable to reproduce populations in storage reservoir especially Pangasiids and Silurids (Amornsakchai *et al.*, 2000). The studied during the year 2001-2002 by Jutagate *et al*. (2005) found that the catch of shark catfish was significantly different between down- and upstream area. It notably increased in two periods: October to November and March to June. The result of %IRI showed that, shark catfish entered to the Mun River from March until June and immigrated to the Mekong River from September to December. Some environmental triggers are believed to activate the migration such as temperature and rainfall (Mekong Secretariat, 1992), threshold river volumes (Singhanouvong *et al*., 1996a), changes in water level and turbidity (Baird *et al*., 2000b; 2001).

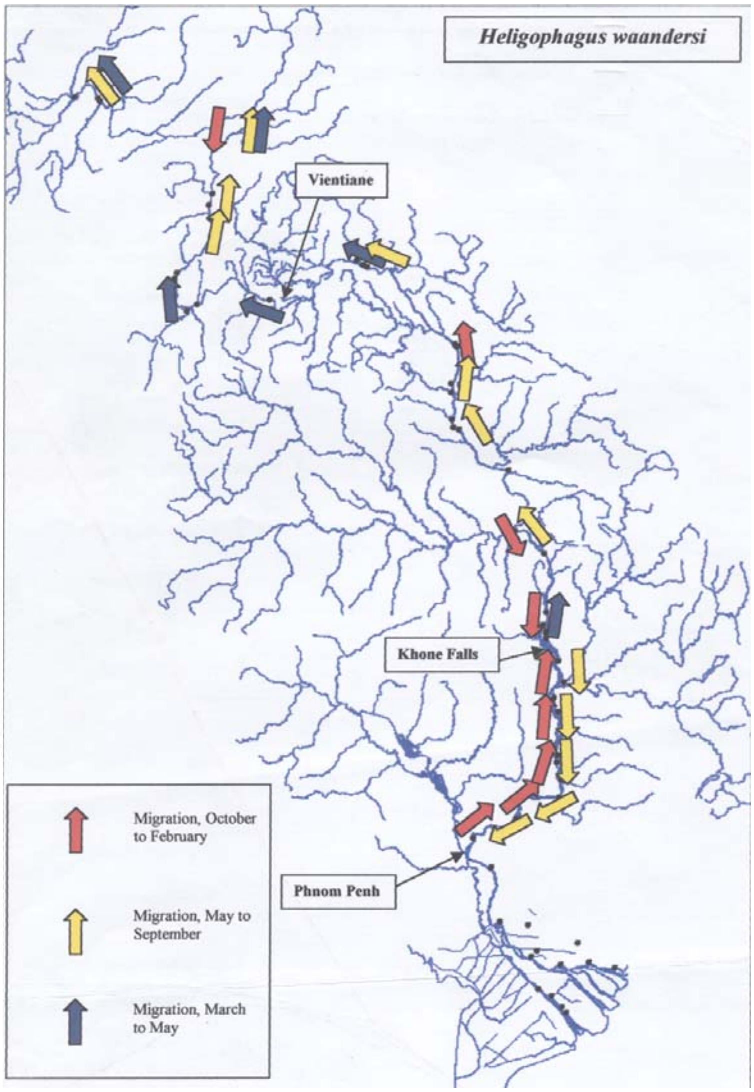


Figure 10 Migration route of shark catfish in Mekong mainstream
Source: Poulsen and Jørgensen (2001)

MATERIALS AND METHODS

Materials

1. Portable YSI model # 60/100 FT for water temperature and turbidity;
2. Gill nets of 4.5, 5.5 and 6.5 mesh size (cm) for gear selectivity study;
3. Hook no. 17 and 18 for gear selectivity study;
4. Steromicroscope for fecundity counting;
5. Measuring board and weighing machine; and
6. Glassware

Methods

1. General Preparations

1.1 Sampling stations

The study was carried out in the Mun River, Ubon Ratchathani Province (15^o N and 105^o E). Five study sites were selected as the representatives of different habitats (Figure 11)

1.2 Fieldwork and data collection

Field sampling was conducted on monthly basis for two consecutive rainy seasons. Fish total length (TL) were measured to the nearest 0.1 cm, body (BW) and gonad weights (GW) were also recorded to the nearest 0.01 g. Length frequency data of shark catfish were collected from three sources: sampled from every fishing gear and local market; from the survey of fishery biologists of Department of Fisheries (DoF) at the same period; and fecundity data. Catches were sex determined and females were further used for biological study. Live females were reared in the 5x5 m^2-floating cages and used as specimens for sex steroid study. Ambient, water temperature and turbidity were *in situ* examined. Rainfall data were obtained from the Ubon Ratchathani meteorological station.

1.3 Field experiment

Experiments on gear selectivity of two types of fishing gear, gillnet and bottom longline, were set up. The experiment was carried out during May through July 2004.

Three mesh sizes of gillnet: 4.5, 5.5 and 6.5 cm were used. Each net is 10 m long and 100 meshes depth. Two sizes of hook for bottom longline, no. 17 and 18, were set. The average width of hook is 6.25 mm (Jutagate and Mattson, 2003).

Riparian fishermen decided by themselves for fishing locations, fishing time and gears to operate. After harvesting, individual fish total length was measured to the nearest 0.1 cm. Number of shark catfish was recorded separately by mesh size. Number of fish recorded from bottom longline with two sizes of hook was mixed.

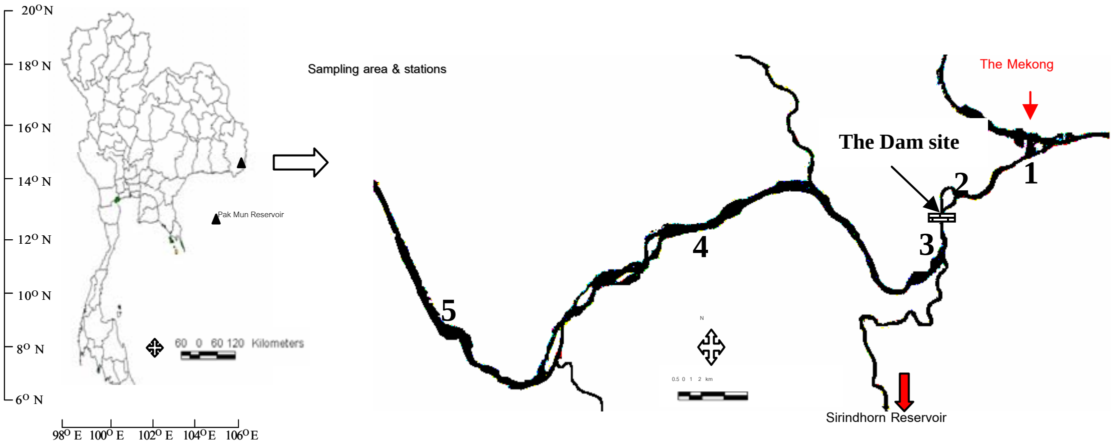


Figure 11 Map of the Mun River and sampling sites.
Station 1: The confluence of Mun River to Mekong at Khong Jiam District,
Station 2: Kang Tana rapid (represents the downstream rapid),
Station 3: The upstream area at dam site, having a creek connect to Sirinthorn Dam,
Station 4: Kang Sa Pue rapid (represents the upstream rapid), and
Station 5: Baan Bua Ta Village, Sawang Weerawong District (represents the flood plain area.)

1.4 Laboratory works

1.4.1 Fecundity: Stage V ovaries were randomly sampled and fixed in Gilson's fluid, shaken vigorously and stored in the dark at least fortnight for studying fecundity (Fe).

1.4.2 Histology: Some ovaries, depend on the available of captured specimens, were stored in Formalin Acetic Acid Calcium-Chloride solution (FAACC: formaldehyde 4%, acetic acid 5%, calcium chloride 1.3%) (Winsor, 1984), for histological study. Samples were done at Department of Pathology, Faculty of Medicine, Chiangmai University. Classification of female fish ovarian tissue in this study was based on the morphological criteria outlined in Table 2.

1.4.3 Sex steroid hormones: Blood samples were taken from caudal vein and kept in syringe contained heparin solution. Samples were centrifuged for 15 minutes at 4,000 rpm. Plasma was stored at -20°C until the analysis (Kestemont *et al.*, 1999). Three sex steroid hormones: testosterone (T.), 17 β-œstradiol (E_2), and 17, 20 β-dihydroxy-4-pregnen-3-one (17, 20-P) were examined by radioimmunoassay (Rinchard *et al.*, 1993) at Faculty of Medicine, Khon Kaen University.

1.5 Data Management

Data were stored in the Microsoft EXCEL files. SPSS program (version 10.0) was used for statistical analyses *i.e.* nonlinear regression analysis. Multiple regression analysis was used for interpreting the relationship between sex steroid hormones and water qualities.

2. Analytical Methods

Monthly samples of both sexes were collected for 19 consecutive months (June 2003 – December 2004). Length-weight relationship was analysed by curvilinear regression analysis. Length frequency distribution (LFD) was constructed for analysing growth, mortality parameters, recruitment, yield/biomass per recruitment, virtual population analysis (VPA) and relationship between fishing mortality (F) and TL.

2.1 Population parameters

2.1.1 Length-weight relationship: A scatter diagram between TL and W was plotted and curvilinear regression analysis was used to determine the relationship as:

$$W = cTL^n \text{.....................} (1)$$

where: c and n are constant values.

Exponent 'n' usually varies around three. When the exponent is statistically significant around three, the pattern of growth is termed 'isometric'. If it is not, the growth pattern is 'allometric'. The coefficients describe the relationship of weight and length vary according to biological and environmental factors (King, 1995).

2.1.2 Estimation of growth parameters: In tropical zone, there is no strong evidence of temperature fluctuation. The age of fish from the annual ring of hard part such as scales and otholiths cannot be reliably estimated (Sparre and Venema, 1998). Therefore LFD data were used to separate each age group. LFD of each month were plotted and input to the Fish Stock Assessment Tools (FiSAT) software package (Gayanilo *et al.*, 1995). Growth parameters, L_∞ and K, were first estimated by Powell-Wetherall sub-routine and scan-K value sub-routine in Electronic Length Frequency Analysis-1 (ELEFAN-1). Then they were used as the input estimators for ELEFAN-1 automatic search routine in FiSAT. Then the growth model was constructed using the von Bertalanffy's growth function (VBGF) (von Bertalanffy, 1938) as:

$$L_t = L_\infty\left(1-e^{-K(t-t_0)}\right)\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Arbitrary age at length zero (t_o) was brought from the hatching time of sutchi's catfish (*Pangasius sutchi*) (NIFI, 1985). The median hatching time is -0.0031 year.

2.1.3 Relative growth performance (ǿ): ǿ or 'phi-prime' are popular used as a best means of averaging growth parameters of a particular species (Pauly and Munro, 1984). It was estimated using the following formula:

$$log\, K = \phi' - 2\, log\, L_\infty \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

2.1.4 Fish maximum age or longevity (t_{max}): Pauly and Munro (1984) also estimated t_{max} from growth parameter as follow:

$$t_{\max} = \frac{3}{K}\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

2.1.5 Total mortality coefficeint (Z): Z was estimated using Jones and van Zalinge equation (Jones and van Zalinge, 1981) in FiSAT sub-routine:

$$ln\, C(L, L_\infty) = a + Z/K\, ln(L_\infty - L)\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where C (L,L_∞) is the cumulative catch of fish of length L and above. The slope of equation (5) is Z/K so that an estimate of Z was obtained from:

$$Z = K \times b\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

2.1.6 Natural mortality coefficient (M) and Fishing mortality coefficient (F): Natural mortality is the mortality from all causes except fishing. In general, M is usually difficult to estimate because we really don't know the exact death of fish population from natural causes. As direct measurement of M is impossible, most of the methods are only 'guesstimates' or 'qualified' guesses (Sparre and Venema, 1998). In this study, Pauly's (1980) empirical formula was applied as:

$$ln\, M = -0.0152 - 0.279\, ln\, L_\infty + 0.6543\, ln\, K + 0.463\, ln\, T\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The fishing mortality coefficient for the time period (F) was derived from:

$$F = Z - M\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

2.1.7 Recruitment Pattern: The recruitment pattern was studied by plotting the percentage of recruitment versus time (month) to obtain the indicator of the seasonal changes in recruitment. The starting point from the LFD data was chosen as a length at first recruitment (L_r). Growth parameters (L_∞, K and t_0) were also used as the input estimators in FiSAT.

2.2 Reproductive biology

Monthly female samples of 19 consecutive months were collected for studying GSI, Fe, ovarian histology and length at 50% maturity (L_m). Total length (TL) and BW were recorded. Ovary of individual fish was removed from body cavity and weighted. The development stage of ovary was classified under the criteria described in Table 1.

2.2.1 Gonadosomatic Index (GSI): GSI was estimated on monthly from the formula:

$$GSI = \frac{GW}{BW} \times 100 \quad ....(9)$$

2.2.2 Fecundity (Fe): Fecundity is defined as the number of ripe eggs in the mature ovary in the spawning season. Eggs were counted gravimetrically (Bagenal and Brown, 1978). Empirical equation between Fe and TL was analysed.

2.2.3 Length at 50% maturity (L_m) : L_m was estimated in two different methods. Firstly, from the relationship among growth parameters, L_∞ and K, and natural mortality coefficient (M) by Mattson (Mattson, 1997) as:

$$L_m = L_\infty \left[\frac{\mathbf{1}}{\mathbf{1} + \left(\frac{M}{\mathbf{3}K} \right)} \right] ....(\mathbf{10})$$

Secondly, L_m was estimated by fitting a logistic function between proportion of cumulative fecundity frequency (P_{Fe}) and TL. This method was modified from probability of capture in trawl selection curve (Sparre and Venema, 1998) as:

$$P_{Fe} = \frac{1}{1 + e^{(a-bTL)}} ....(11)$$

By applying a few algebraic manipulations, the length at which ranged from 25% to 75% which is symmetrical around 50% is ‘effective range to be a good mother’. Therefore, the length at 50% is L_m. The formulas for calculating are:

$$L_{25\%} = \frac{(a - \ln 3)}{b} \text{....................}(12)$$

$$L_{50\%} = \frac{a}{b} \text{....................}(13)$$

$$L_{75\%} = \frac{(a + \ln 3)}{b} \text{....................}(14)$$

2.2.4 Ovarian histology: Ovarian tissues were fixed in FAACC solution at least fortnight. Tissues were embedded in paraffin, sectioned, stained with hematoxylin and eosin. The examination of developmental stage was done under the light microscope and digital photography. Classification was based on the morphological criteria as described in Table 1 and followed by the report of Murua and Saborido-Ray (2003).

2.3 Fisheries

2.3.1 Relative yield per recruit ((Y/R)′): In fisheries management, it is important to be able to determine changes in the Y/R for different values of F (Sparre and Venema, 1998). Therefore, Beverton and Holt (1962) therefore developed a ‘relative yield per recruit model’ which can provide the kind of information needed for management. This model has a great advantage requiring the category of length-based models which defined by:

$$\left(Y/R\right)' = E \times U^{M/K} \times \left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\right] \text{....................}(15)$$

where $m = K/Z$;

$U = 1 - \frac{L_c}{L_\infty}$ = the fraction of growth to be complete after entry into the exploited phase; and

$E = F/Z$ = the exploitation rate or the fraction of deaths caused by fishing

2.3.2 Average biomass per recruit ($\bar{B}/R$): $\bar{B}/R$ was applied by Beverton and Holt (Sparre and Venema, 1998). This model expresses the annual average biomass of survivors as a function of mortality (or effort). It is closely related to yield per recruit model so that fishery biologist was recommended to calculate both Y/R and $\bar{B}/R$.

The formula used to calculate $\bar{B}/R$ is:

$$\overline{B}/R = e^{[-M(t_c - t_r)]} \times W_\infty \times \left[\frac{1}{Z} - \frac{3s}{Z+K} + \frac{3s^2}{Z+2K} - \frac{s^3}{Z+3K}\right] \text{....................}(16)$$

where: s = $e^{[-K(t_c - t_0)]}$

t_c = age at first capture
t_r = age at recruitment

W_∞ = asymptotic body weight

In the case of F=0, the value of $\overline{B}/R$ is the so-called 'virgin biomass per recruit'(Bv/R). Bv/R is the biomass of unexploited stock (Sparre and Venema, 1998).

2.3.3 Estimation of stock size: Length-based cohort analysis was used to estimate stock size that modified by Sommani (1987) under the condition of high growth and mortality rates. The input parameters were: catch in number at each lower limit length class, growth parameters (L_∞, K and t_o), mortality parameters (M and 'terminal F'), and exploitation rate (E). The step of calculation was clearly complied in Thapanand (2002).

2.3.4 Estimation of fishing mortality at Jones' length-based cohort analysis: In the classical fishery assessment, fishery biologist usually assumed that F at any length of fish is constant (Beverton and Holt, 1957), or vary seasonally with a very short life span dividing (Ricker, 1958, 1975). But in general, such assumptions are not reasonably use in many cases of fisheries. F varies with the length of fish according to the selectivity of fishing gears (Sparre and Venema, 1998). Sommani (1988) modified a function which proved the variation of F throughout the length. The model is created under the assumption that F increases as the length increased but becomes asymptotically constant at the asymptotic length. Sommani's function is described as follows:

$$F = \alpha e^{\frac{-\beta}{(L_{i1} - L_0)}} \text{....................}(17)$$

where α = the actual upper limit of F when the length of fish become infinite;

L_0 = the length at which F is zero

β = constant

2.3.5 Gillnet selectivity:

a. Estimation of optimum length for being caught (L_c): Bell-shaped selection curve was used to estimate the selectivity of gillnet (Holt, 1963). Selection factor (SF), optimum length for being caught (L_c) and common standard deviation (S) were estimated by the following equations:

$$SF = \frac{-2a}{b(m_a + m_b)} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{18})$$

$$L_c = SF \times m_a \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{19})$$

$$S = \sqrt{SF * \frac{(m_b - m_a)}{b}} \ldots\ldots\ldots\ldots\ldots (\mathbf{20})$$

b. Single mesh selectivity curve: Matched two contiguously mesh size, 4.5 via 5.5 and 5.5 via 6.5 cm, for computing the L_c separately. In each pair: Single selectivity curves were constructed using the expected values of selection as described in equation (15) and (16). Summed up the expected value of selection and constructed the common selection curve as the representative. The X-intercept of the linear regression equation from Holt (1963) was the 'common' L_c. Selection factor was also estimated.

$$S_{a_L} = e^{\left(-\frac{(L-L_{ma})^2}{2S^2}\right)} \ldots\ldots\ldots\ldots\ldots (\mathbf{21})$$

$$S_{b_L} = e^{\left(-\frac{(L-L_{mb})^2}{2S^2}\right)} \ldots\ldots\ldots\ldots\ldots (\mathbf{22})$$

c. Multi-meshes selectivity curve: Index of the number in the population for each mesh size was estimated, using equation (17) and (18), and summed up as a representative from each pair. Each pair of mesh sizes are averaged into 5.0 and 6.0 cm for multi-meshes selection. Computed L_c and constructed selectivity curve by the same process as the topic 'b'. The selection curve would be explained in term of three mesh sizes of gillnet.

$$N_{a_L} = \frac{C_{a_L}}{S_{a_L}} \ldots\ldots\ldots\ldots\ldots (\mathbf{23})$$

$$N_{b_L} = \frac{C_{b_L}}{S_{b_L}} \ldots\ldots\ldots\ldots\ldots (\mathbf{24})$$

d. Various Sizes Model: Computed model for various mesh sizes using the method described by Sparre and Venema (1998). A common selection factor was also estimated. Optimum mesh size for shark catfish gillnetting was decided by Comparing the L_c with L_m.

2.3.6 Hook selectivity: L_c from hook was estimated in two different methods. Firstly, L_c was estimated from probit analysis which compiled by Thapanand (2000). The L_c was calculated by substituting the probit value of five.

Secondly, L_c was estimated by fitting a logistic by the method of probability of capture in trawl selection curve as the same process of the estimation of L_m (Sparre and Venema, 1998).

The length at which ranged from 25% to 75% which is symmetrical around 50% is ‘selection range’. Therefore, the length at 50% is L_c, respectively.

Optimum hook size for shark catfish which estimated from both methods was decided by comparing the L_c with L_m.

RESULTS AND DISCUSSION

Population Parameters

1. Length-weight Relationship

One hundred and sixteen (116) length-weight data of shark catfish, with the size ranged from 3.1 – 50.2 cm (TL), were from field sampled in this study and the survey of fishery biologists from the Department of Fisheries (DoF) at the same period (Appendix Table 1). The data from Appendix Table 1 showed unequal variances. Weighted least square regression analysis was used for estimating the relationship by using the frequency of fish body weight as a weighting factor (Appendix Table 2 and Figure 12) (Steel and Torrie, 1986). The empirical equation between length and weight of *H. waandersii* in the Mun River is:

$$W = \mathbf{0.0076}TL^{\mathbf{2.9582}} \text{.....................}(\mathbf{25})$$

The exponent, b, was not significantly different from 3 (P>0.05). Therefore, the growth pattern of this species is 'Isometric' and the length-weight relationship can be written in terms of the cube law as:

$$W = \mathbf{0.0067}TL^{\mathbf{3}}\,;R^{\mathbf{2}} = \mathbf{0.9904},S_{y.x} = \mathbf{0.2437},n = \mathbf{39}\text{.....................}(\mathbf{26})$$

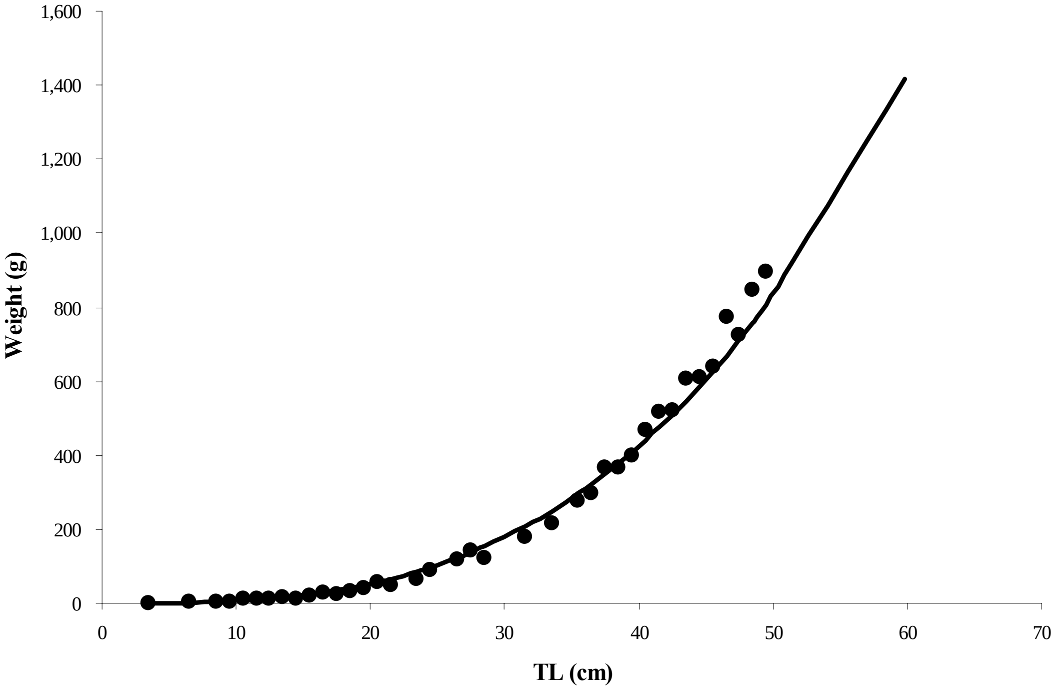


Figure 12 Length-weight relationship of shark catfish in the Mun River.

The length-weight relationship is different from the report of Singhanouvong *et al*. (1996a), $W = 0.0008TL^{3.549}$, which they sampled from the Mekong River at Hoo Som Yai, Champasak Province in Lao PDR. The fish size ranged from 23.7 – 45.0 cm TL, which had a narrower range comparable to this study.

Nongkhai Inland Fisheries Station (1985) reported the length-weight relationship of male and female shark catfish as: $W = 0.0403L^{2.494}$ and $W = 0.0027L^{3.231}$ for parental males and females, respectively.

2. Growth Parameters

The size distribution range from 6.0 – 54.0 cm (TL) (Appendix Table 3 and Figure 13) was classified in 1-cm interval. A 19 consecutive months of LFD were used to estimate growth parameters with three trials. The arbitrary age at length zero, t_0, was estimated from the median hatching time of Sutchi's catfish (*Pangasius sutchi*) was 27 hours or -0.0031 year (NIFI, 1985).

1.1 Trial 1: Bhattacharya's method and linking of means (Bhattacharya, 1967)

The modes of length group using Bhattacharya's method in FiSAT software program were shown in Table 6. There were many possibilities to link of means. A dot line was selected to estimate the growth parameters (Figure 14). Walford method was used under the assumption of non-seasonal growth (Sparre and Venema, 1998) (Figure 15). The von Bertalanffy's growth function (VBGF) in term of TL from this trial was:

$$L_t = \mathbf{63.68}\left(\mathbf{1} - e^{-\mathbf{1.08}(t+\mathbf{0.0031}))}\right) \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{27})$$

1.2 Trial 2: Automatic Search Routine in FiSAT with a seasonal growth.

Due to the low catch in December 2003 to February 2004 and November – December 2004; these data were excluded from the estimation. A Powell-Wetherall sub-routine was used for estimating the input parameters of L_∞ and scan-K value sub-routine was used to estimate K. The estimated L_∞ was 60.47 cm TL and K was 1.8 per year. An automatic search routine, with the seasonal growth of 0.5 both in amplitude of oscillation and winter point, estimated the VBGF as: (Figure 16)

$$L_t = \mathbf{60.47}\left(\mathbf{1} - e^{-\mathbf{1.8}(t+\mathbf{0.0031}) - \frac{\mathbf{0.9}}{\mathbf{2}} sin(\mathbf{2}\pi t)}\right) \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{28})$$

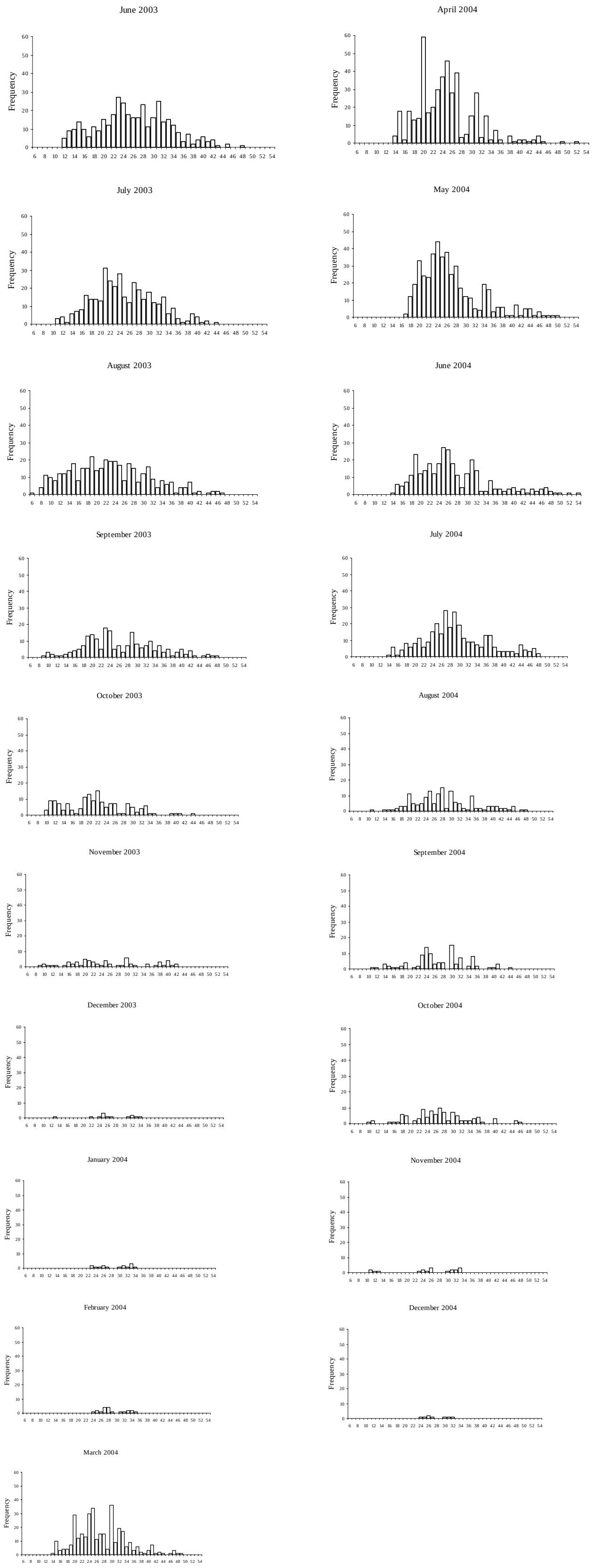


Figure 13 Monthly length frequency distribution of shark catfish in the Mun River during the study period.

Table 6 Length mode of shark catfish from Bhattacharya's method.

Month	**Length Mode**					
	1	**2**	**3**	**4**	**5**	**6**
Jun-03	14.64	24.46	32.63	40.15		
Jul-03	17.09	22.83	29.78	37.76		
Aug-03	12.71	21.11	26.78	32.44	39.08	45.50
Sep-03	10.50	20.61	32.02	41.02	46.00	
Oct-03	12.89	21.77	31.25			
Nov-03	10.50	19.53	30.50	40.76		
Dec-03	25.50	32.50				
Jan-04	25.50	32.04				
Feb-04	26.50	33.11				
Mar-04	22.20	30.75	37.84	45.58		
Apr-04	19.37	25.63	31.01	36.01	42.26	
May-04	24.50	34.47	39.52	44.59		
Jun-04	20.35	27.70	36.08	40.76	46.16	
Jul-04	19.79	27.66	35.00	44.63		
Aug-04	20.06	28.01	36.01	41.43		
Sep-04	13.44	23.45	34.06			
Oct-04	22.40	28.69	34.30	44.50		
Nov-04	24.00	31.50				
Dec-04	26.00					

2.3 Trail 3: Automatic Search Routine in FiSAT with non-seasonal growth.

This trial used maximum length estimation from FiSAT sub-routine. This routine estimates the maximum length of fish in a population, based on assumption that the observed maximum length of a time series of samples does not refer to a fixed quality but, rather represent a random variable which follows a probabilistic law (Formacion *et al.*, 1991). The maximum length was used as an initial estimate of L_∞ in automatic search routine in ELEFAN-1 and scan-K value was used to estimate initial K value.

From this trial, the maximum length was 59.74 cm (TL) and K was 1.32 per year. An automatic search routine, with non-seasonal growth, estimated the VBGF as: (Figure 17)

$$L_t = \mathbf{59.74}\left(\mathbf{1} - e^{-\mathbf{1.32}(t+\mathbf{0.0031})}\right)\ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{29})$$

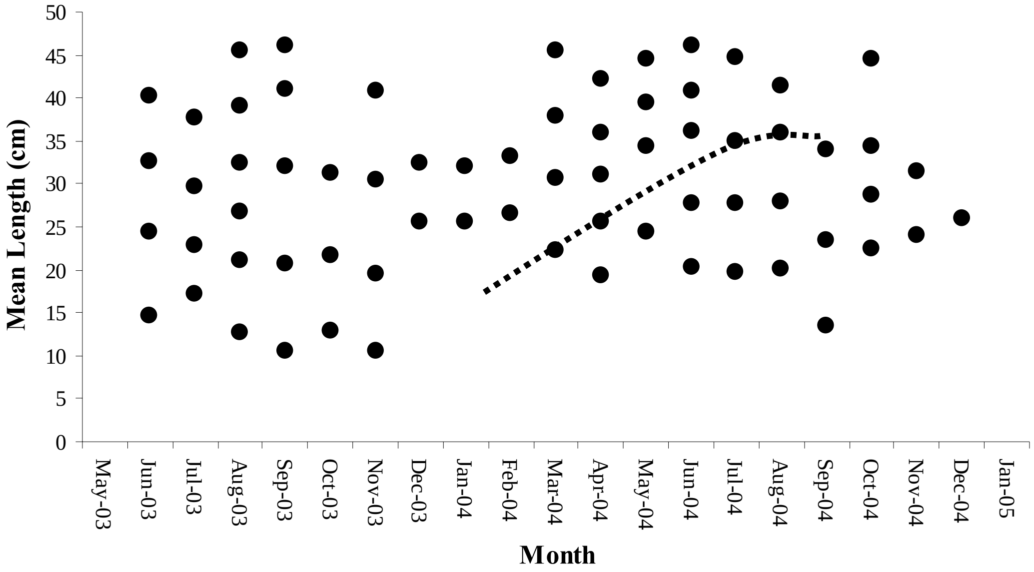


Figure 14 Presented modes of shark catfish in the Mun River from Bhattacharya's method. A dot line was selected progressive growth.

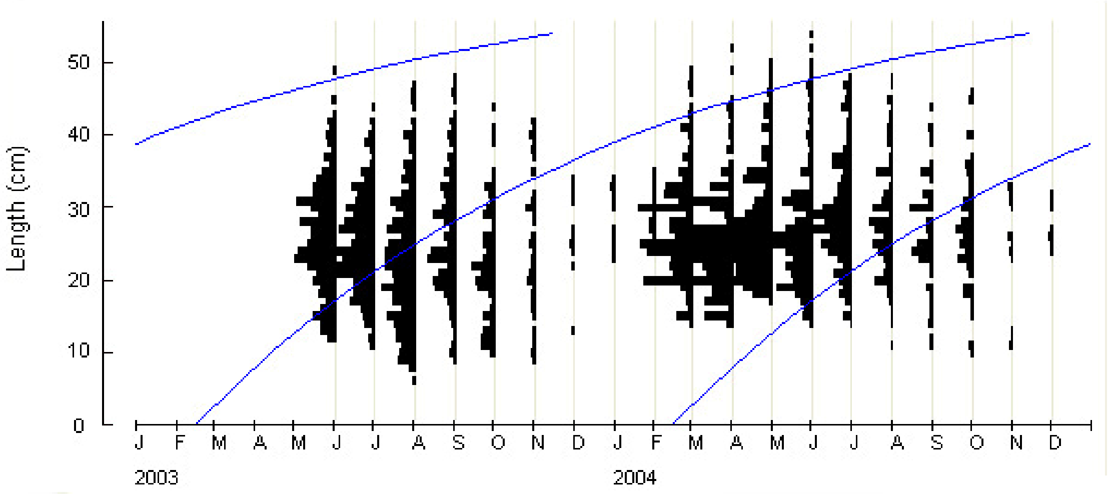


Figure 15 The VBGF of shark catfish in the Mun River from trial 1.

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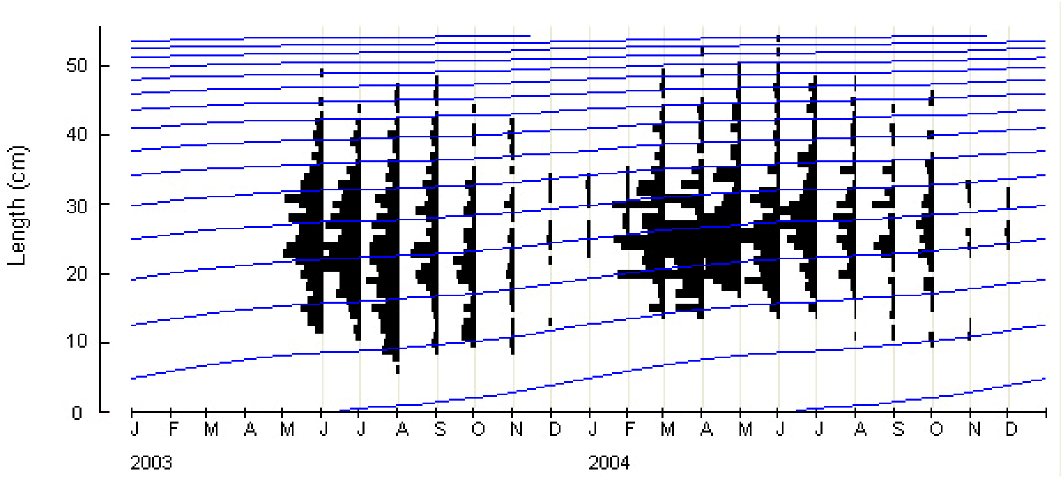


Figure 16 The VBGF of shark catfish in the Mun River from trial 2.

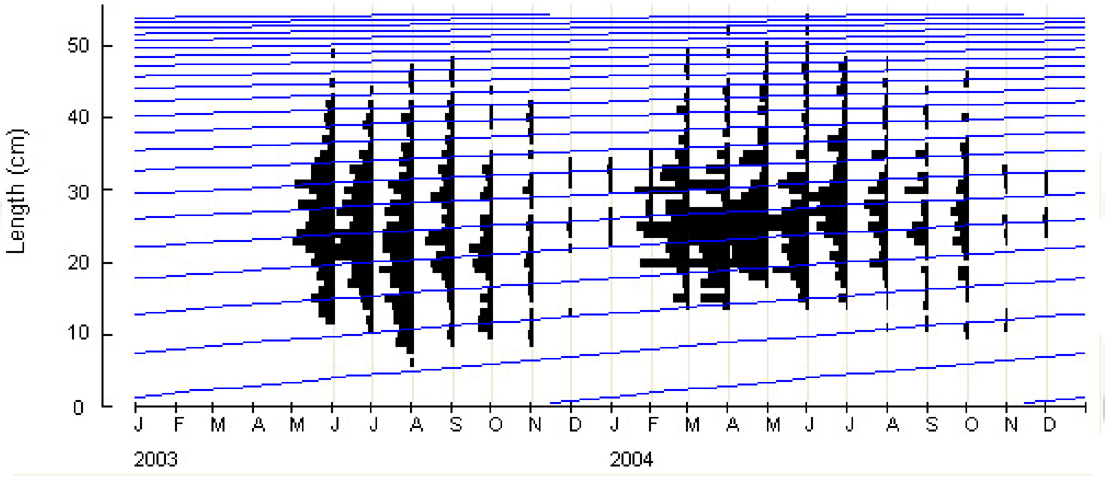


Figure 17 The VBGF of shark catfish in the Mun River from trial 3.

The relative growth performance and longevity of shark catfish from all trials were also estimated and concluded in Table 7.

Table 7 Growth parameters of shark catfish in the Mun River comparing with three different trials.

Trial	**K (year)$^{-1}$**	**L_∞ (cm)**	**Ǿ**	**WP**	**C**	**R_n**	**t_{max*} (year)**
1	1.08	63.68	3.641	0	0	0.101	2.78
2	1.8	60.47	3.818	0.5	0.5	0.16	1.67
3	1.32	59.74	3.673	0	0	0.196	2.27

* estimated from eq. (4)

The result from Bhattacharya's method (Table 6) showed that shark catfish comprised of multiple cohorts; the general type in tropical species. However, the maximum size in this study was bigger than the report of Singhanouvong *et al.* (1996a). From Table 7, the most reliable growth parameters should be the third trial. It is therefore the estimation of L_∞ should be closely related to its maximum size from the samples (Pauly and Munro, 1984). Growth constant, K, determines how fast the fish approaches to L_∞. In tropical fish with a short life span, they almost reach their L_∞ within a year or two and have a high value of K (Sparre and Venema, 1998). The result from FiSAT showed the rapid growth rate of shark catfish which was consistence with the concept of tropical fish growth.

As water quality record, monthly water temperature was not much different as shown in Appendix Table 7, the non-seasonal growth should be an appropriate for constructing VBGF. Moreover, the third trial also gave the higher R_n value than the second one which tried on a seasonal growth.

Arbitrary age at length zero, t_0, is the age of fish when fish has zero length. In biological sense the growth begins at hatching. After the larva hatch, it already has a length or L_0 (Sparre and Venema, 1998). The L_0 is the Y-intercept in VBGF and easy to estimate t_0 by rearranging the VBGF. Some fish that cannot evaluate L_0, its hatching time is acceptable. For shark catfish, it has not both L_0 value and hatching time. Then, the t_0 value which used in this study was obtained from sutchi's catfish because it is closely relative. Nevertheless, NIFI (1985) could induced spawning sutchi's catfish but reported the hatching time in term of 'range' in hour, hence, the 'median' hatching time was suitable for using as t_0 in this study instead of using the 'mean'.

From eq. (29) and isometric growth pattern of shark catfish, the VBGF in term of body weight was described as:

$$W_t = \mathbf{1{,}415.203}\left(\mathbf{1} - e^{-\mathbf{1.32}(t+\mathbf{0.0031})}\right)^{\mathbf{3}} \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{30})$$

Relative growth performance (ϕ') can check the reliability in estimating L_∞ and K values. According to ϕ' is constant in the regression between log K and log L_∞ as defined in eq.(3), ϕ' should be closed within the same species with different data set (Sparre and Venema, 1998). Moreover, species within the same family should have similar ϕ', if ϕ' is normally distributed (Moreau, *et al.*, 1986). *Pangasius pangasius,* which is also Pangasiid had the average ϕ' of 3.273 (Froese and Pauly, 2004). In the present study, the ϕ' value from the third trial was 3.673, and had the similar pattern as suggested by Moreau, *et al.* (1986).

If the selected VBGF came from the third trial, the expected growth curve would be shown as Figure 18:

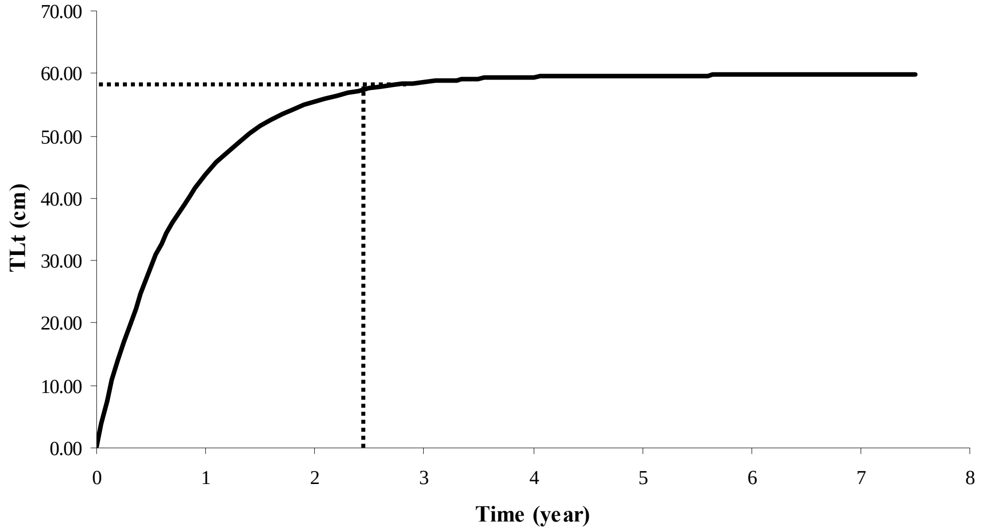


Figure 18 Expected VBGF from the third trial.

The longevity of shark catfish that estimated from eq. (4) is about two year and four months. At this age, the expected length of shark catfish is 57.24 cm, 2.5 cm smaller than L_∞ (59.74 cm), which can be accepted for tropical fish (Figure 18). In tropical waters, fish growth rates are faster, maturation at the younger of age and the life span usually shorter than in temperate waters. Tropical fishes show a wide range of sizes and growth rates. Some small cyprinodonts are annual, completing their life cycles in less than one year (Lowe-McConnell, 1975). Larger species may live in many years such as Mekong *Pangasianodon hypophthalmus* in Cambodia, sexual maturation takes more than three years. Then, its longevity should not less than three years (van Zalinge, *et al.*, 2002.).

When compared to Asian redtail catfish, *Hemibagrus nemurus*, in Sirinthorn Reservoir, it had longevity about 4.1 years (Jutagate, 2004). Pianka (1970) suggested that carnivorous catfishes mostly have long life spans which are ‘K-selection’ type. Therefore, the reasonable longevity of shark catfish should be between two years four months to three years as defined by VBGF.

3. Mortality Parameters

The average surface water temperature (Appendix Table 7) in the Mun River throughout the study was 28.7^{o}C. Mortality parameters were estimated as shown in Table 8. Exploitation rate, ($E = \frac{F}{Z}$), is the fraction of deaths caused by fishing was also be computed.

Table 8 Mortality parameters of shark catfish in the Mun River.

Z $(year)^{-1}$	M $(year)^{-1}$	F $(year)^{-1}$	E
4.863	1.7853	3.0777	0.633

Exploitation rate of shark catfish showed that almost over 60% of fish was utilised by fishing. The F-value was transformed in the unit of per month and later used as a ‘terminal F’ in estimating of stock size.

The monthly mortality coefficients, Z and F, were derived from Wetherall’s sub-routine in FiSAT as defined in Table 9. The magnitude of mortality by month is shown in Figure 19.

Table 9 Monthly total (Z) and fishing (F) mortality coefficients.

Month	Z/K	Z $(month)^{-1}$	F $(month)^{-1}$	Fishing Status	Gates Operation
Jun-03	5.396	0.594	0.445	Closed season	Closed Gates
Jul-03	3.794	0.417	0.269		
Aug-03	3.447	0.379	0.230		
Sep-03	3.025	0.333	0.184		
Oct-03	3.695	0.406	0.258	Fishing season	Open Gates
Nov-03	1.445	0.159	0.010		
Dec-03	1.259	0.138	-0.010		
Jan-04	0.835	0.092	-0.057		
Feb-04	1.697	0.187	0.038		
Mar-04	4.241	0.467	0.318		
Apr-04	5.479	0.603	0.454		
May-04	4.683	0.515	0.366	Closed season	Closed Gates
Jun-04	3.813	0.419	0.271		
Jul-04	4.352	0.479	0.330		
Aug-04	3.226	0.355	0.206		
Sep-04	2.744	0.302	0.153		
Oct-04	3.553	0.391	0.242	Fishing Season	Open Gates
Nov-04	0.865	0.095	-0.054		
Dec-04	0.494	0.054	-0.094		

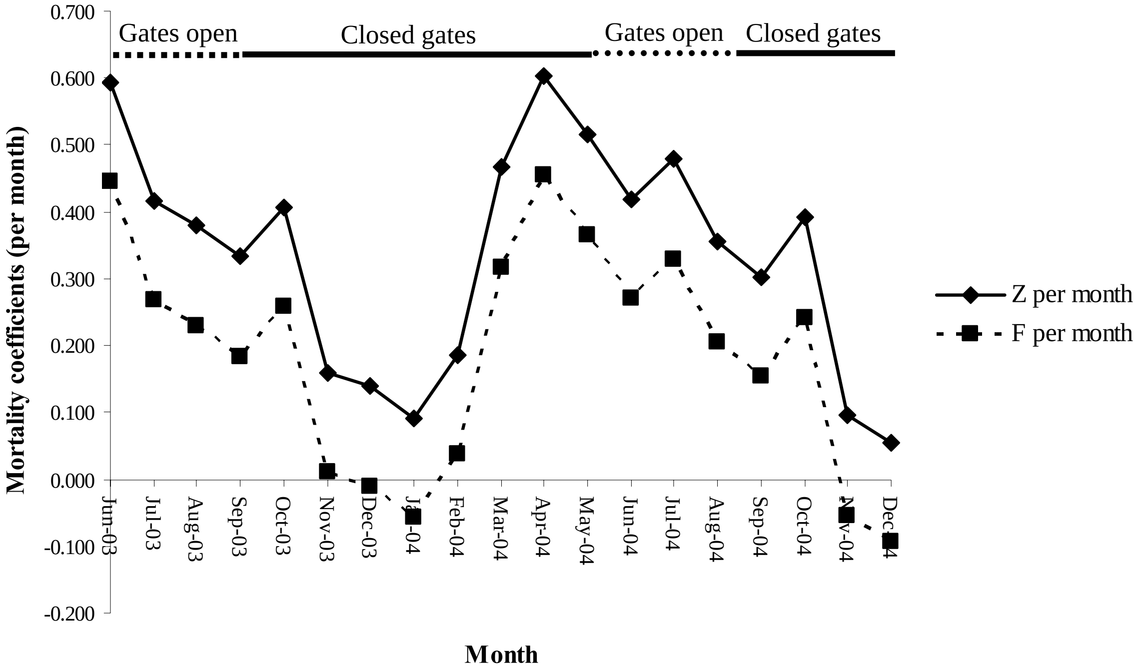


Figure 19 Variation in the monthly total (Z) and fishing (F) mortality coefficients throughout the study period.

The highest mortality coefficient of shark catfish is in March and then decreased until August that overlapped between late dry - to late wet season. In the dry season, especially from November through February, the catch was very low and also gave the low rate of Z values. After minus with M, the F-values were less than zero. It was an un-reliable value under the assumption of mortality coefficients.

During the study period, the sluice gates of Pak Mun Dam were opened for four months during May – August in both years and the catch were high. It depends on the monsoon season which provided a wide spread of flood plain. The riverine fishes respond to the floods, which arrive after the local rains have precipitated, by lateral movements out over flooded plain and upstream movement for feeding and spawning (Lowe-McConnell, 1977).

4. Recruitment Pattern

The recruitment pattern of shark catfish was plotted between the percentages of recruitment against time (Figure 20). It projected a set of LFD backward onto a one-year time axis. The percentage of monthly recruitment is shown in Table 10.

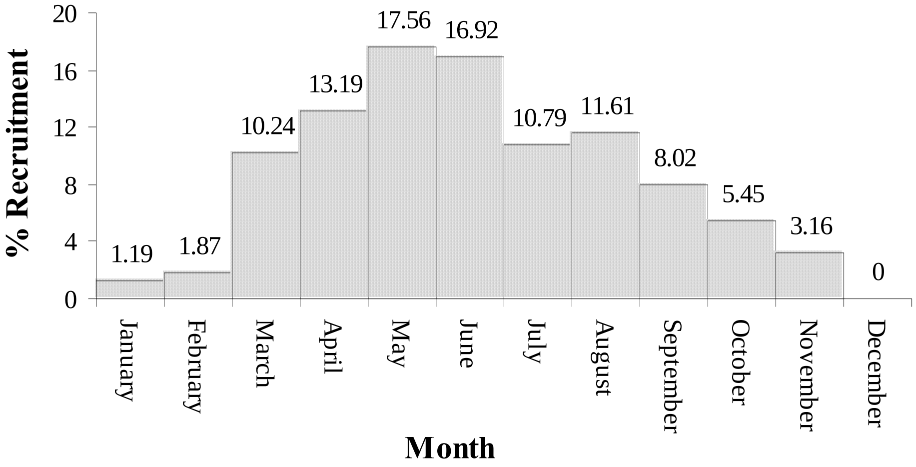


Figure 20 The percentage monthly recruitment of shark catfish.

Table 10 Percent recruitment of shark catfish.

Month	Percent Recruitment
January	1.19
February	1.87
March	10.24
April	13.19
May	17.56
June	16.92
July	10.79
August	11.61
September	8.02
October	5.45
November	3.16
December	0.00

The recruitment of shark catfish appears every month with difference percentage. Overall recruitment pattern has one peak in a year with the noticeable peak during March to August. It was indicated that shark catfish in the Mun River has prolong spawning season during wet season so that it gave recruitment in one prominent peak with a prolong month. This was quite similar to those tropical fish species such as Thai river sprat (Jutagate, 2002), cypriniids (Moreau and Sricharoendham, 1999) and Nile tilapia (Virapat, 1993). The peak of recruitment should be considered for closed area fishing season managed by DoF. In the Mun River, the closed season is enforced during 16th May to 15th September which is the same period of recruitment peak of shark catfish. It was seen that the period of closed fishing season was suitable for recruited fishes. Other influences to increase the recruitment might be a higher water level from rainfall with corresponds to the increasing of spawning ground and also feeding habitat.

Reproductive Biology

1. Sexual Characteristics

Shark catfish could not clearly express the secondary sexual characteristic except during the period of spawning that the difference between male and female shark catfish could be distinguishable observed. For female, the belly is enlarged, swelled, white and round shape. Genital pore is magnified, round and reddish. Male, has a protrude papillae at genital pore and smaller size of the pore than female. The belly is stiffer than female. Sex ratio during the spawning season is 1:1 (Nongkhai Inland Fisheries Station, 1985).

2. Gonadosomatic Index

The monthly average GSI of female shark catfish in each sampling station is shown in Table 11. The magnitude of average GSI could be displayed in Figure 21.

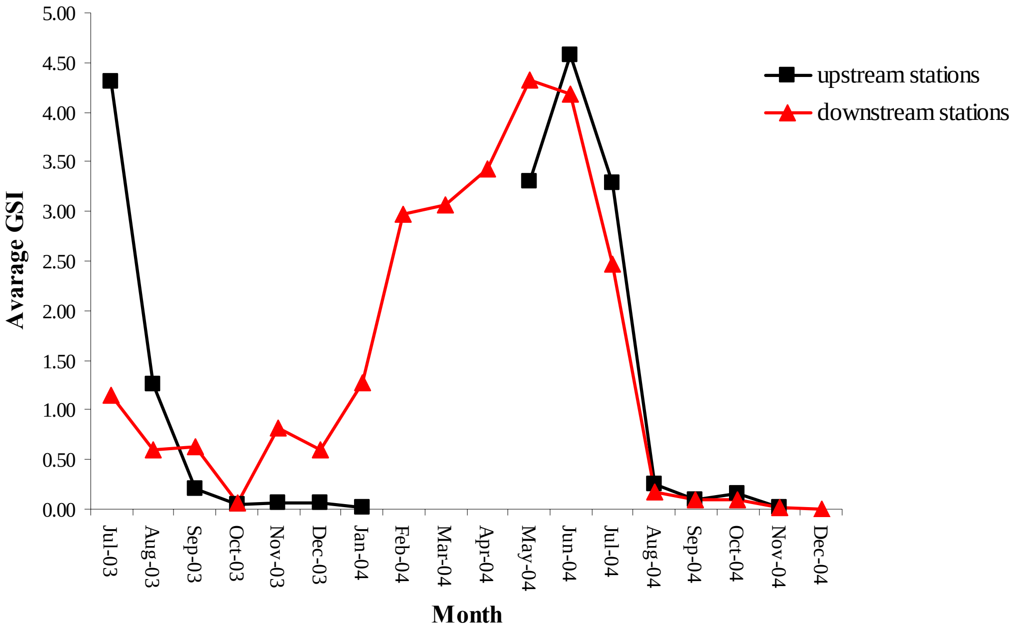


Figure 21 Monthly GSI of female shark catfish.

Table 11 Average GSI of shark catfish.

Month	Station	
	upstream	**downstream**
Jul-03	4.310	1.140
Aug-03	1.260	0.600
Sep-03	0.200	0.630
Oct-03	0.040	0.070
Nov-03	0.070	0.810
Dec-03	0.070	0.590
Jan-04	0.010	1.270
Feb-04	n.d.	2.970
Mar-04	n.d.	3.070
Apr-04	n.d.	3.430
May-04	3.300	4.320
Jun-04	4.580	4.180
Jul-04	3.280	2.470
Aug-04	0.250	0.180
Sep-04	0.090	0.090
Oct-04	0.150	0.090
Nov-04	0.010	0.020
Dec-04	n.d.	0.025

n.d. = no data

Gonadosomatic index (GSI) is a useful parameter for evaluating the breeding cycle of fish. After eggs are spent, the GSI will markedly decrease. Wootton (1992) suggested sub-tropical and tropical fishes usually have an extended breeding season with females spawning many times and show small changes in the amplitude of the GSI. In this study, the variation of GSI during two cycles of sampling was peaked in the same period, May to July, which is the beginning of the rainy season.

The magnitude of GSI, compared with up- and downstream stations, the result showed the relative GSI values. The GSI of downstream and upstream are paralleled trends month by month. The GSI of downstream stations were higher than upstream stations from January to April 2004. Then the GSI of upstream stations were higher than downstream stations from June to October 2004. There were not samples during the dry season in the upstream areas, February-April and December 2004.

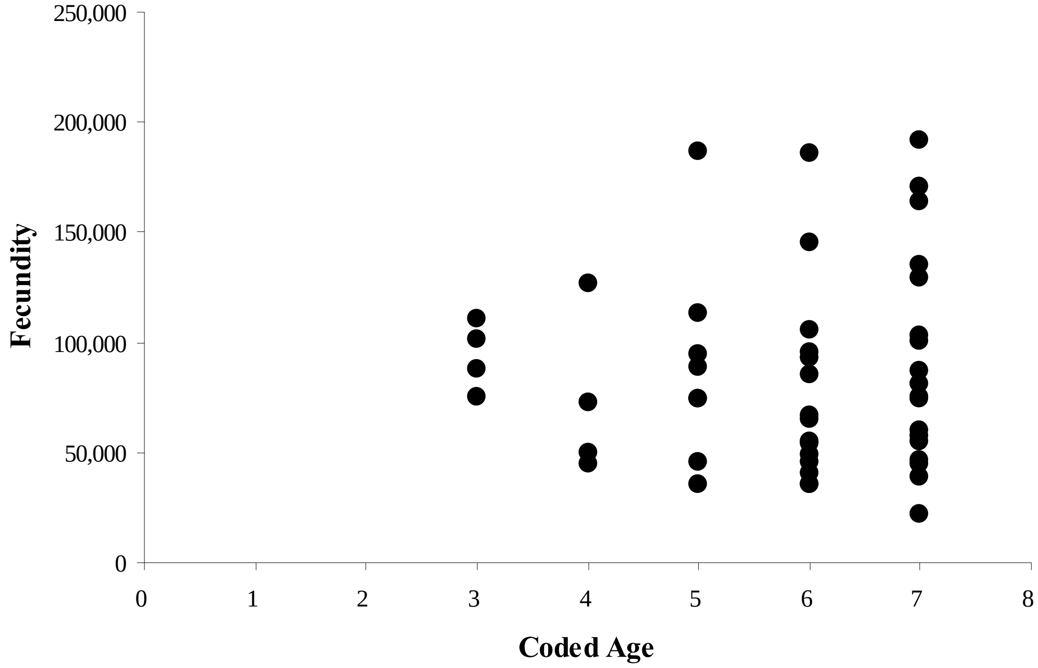
Most of silurids species are rapids-dependent (Amornsakchai *et al.*, 2000). For example, *P. hypophthalmus* in LMB, the spawning takes place in the stretch of the Mekong River between Kratie town and the Khone Falls on the Cambodian/Lao PDR.

border. The habitat consists of rapids and sandbanks, interspersed with deep rocky channels and pools (van Zalinge *et al.*, 2002). From this study, the mature females with stage-V ovaries were caught more in downstream, where the rapids are located. It can be said that rapids in the Mun River are the spawning grounds of shark catfish.

3. Fecundity

Egg character of shark catfish is rounded-shape with an average diameter of 1 mm. Ripened egg is pale-yellowish colour, transparent and glossy. The egg type is demersal and sticky after absorbed water.

The profile of monthly fecundity is shown in Appendix Table 5 and Figure 22.



Notice: Coded Age 1 = January 2004

Figure 22 Fecundity profile of shark catfish.

Average fecundity in each month had high variances depend on the size of female fish. No evidence of mature females and spawning activities during January-February 2004 and August 2004. The trend of mature females was high from May to July and corresponding to GSI.

Fecundity was widely ranged from 21,547– 191,539 eggs, with a mean of 85,174±43,206 eggs. It is statistically different ($P<0.05$) with 138,443 eggs under pond condition reported by Insiripong (2001). Nongkhai Inland Fisheries Station (1985) reported the fecundity of shark catfish broodstock, that was higher than this study, for female with TL = 38.5 cm, BW = 300 g, GW = 32.5 g had 82,500 eggs whilst the female with BW = 1,500 g, GW = 100 g had 190,000 eggs.

Fecundity per length groups was presented in Appendix Table 6. Typically, the relationship between fecundity and length is estimated in power function (Figure 23) as:

$$Fe = \mathbf{6.955}TL^{\mathbf{2.4533}}; R^2 = \mathbf{0.4813}, S_{y.x} = \mathbf{0.3182}....................(\mathbf{31})$$

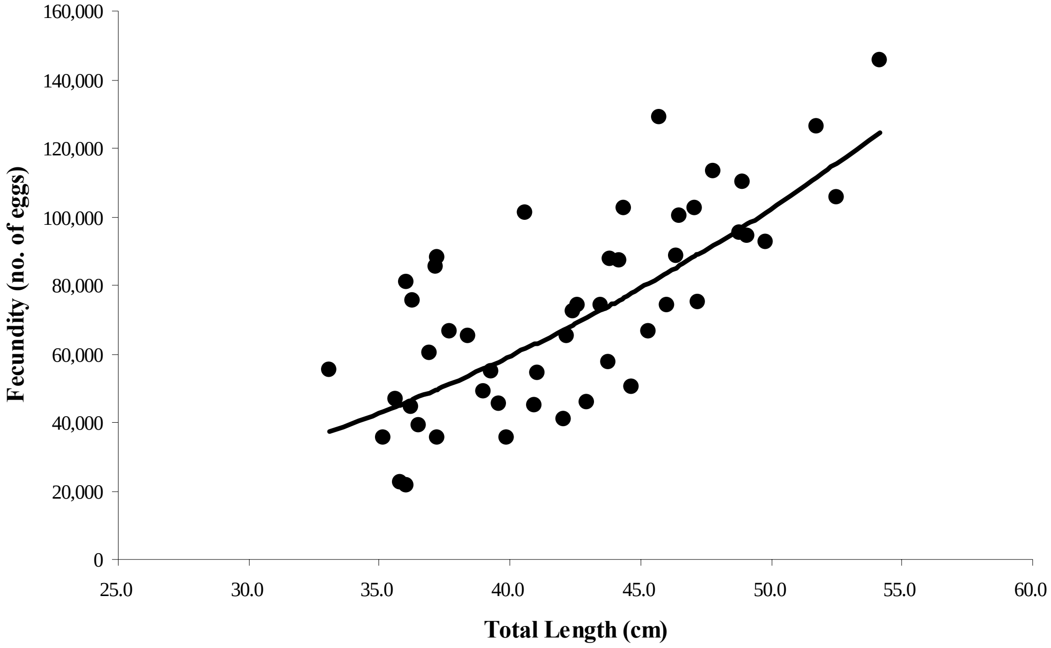


Figure 23 Length-fecundity relationship of shark catfish in term of power function.

The situation normally occurs in a study on fecundity and length-fecundity relationship in many aquatic fishes is a widely variation of fecundity in the same length class. It may effect from the behaviour of females which are multiple-spawner in the same spawning season (Bagenal, 1966). De Silva *et al.* (1985) stated that environmental factors also be an important factors in the variation of fecundity. For this reason, it usually makes the low correlation of length-fecundity relationship. In addition, the fecundity by length seems to be unconfirmed with power function. It is the fact that the production of eggs is regulated by sex hormones. When mature female fish produces eggs, fecundity will increase dramatically with size and dropped after the fish reaches the size at physiologically not produces the sex hormones.

After focusing on this phenomenon, this study presents the new mathematical function to find out the most fitting in biological sense of fecundity both in fishes and invertebrates; based on their life histories. The model can estimate the first size that fish mature and fitted both the natural and rearing conditions.

For the mathematical sense, the assumptions are as follows:

1. At the X-intercept point, it is the first size at fish mature (cutoff size to be a parental stock);

2. The increase of fecundity should be non-linear and limited; and

3. The rate of increasing of fecundity should be regressed by size.

The result from this study revealed that a logarithmic function is the best fit function which could be expressed as:

$$Fe = b\,ln(L) - a \ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(32)}$$

and the length at first mature (L_{fm}) of fish was:

$$L_{fm} = e^{\frac{-a}{b}} \ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(32)}$$

Hence, the length-fecundity relationship from this study was

$$Fe = \mathbf{169757.17}\,ln(TL) - \mathbf{561742.42}, R^{\mathbf{2}} = \mathbf{0.5206}, S_{y.x} = \mathbf{20194} \ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(33)}$$

and L_{fm} was 27.36 cm TL (Figure 24) and the area within the red-dotted line is the effective range to be a good mother which estimated from the 4th topic.

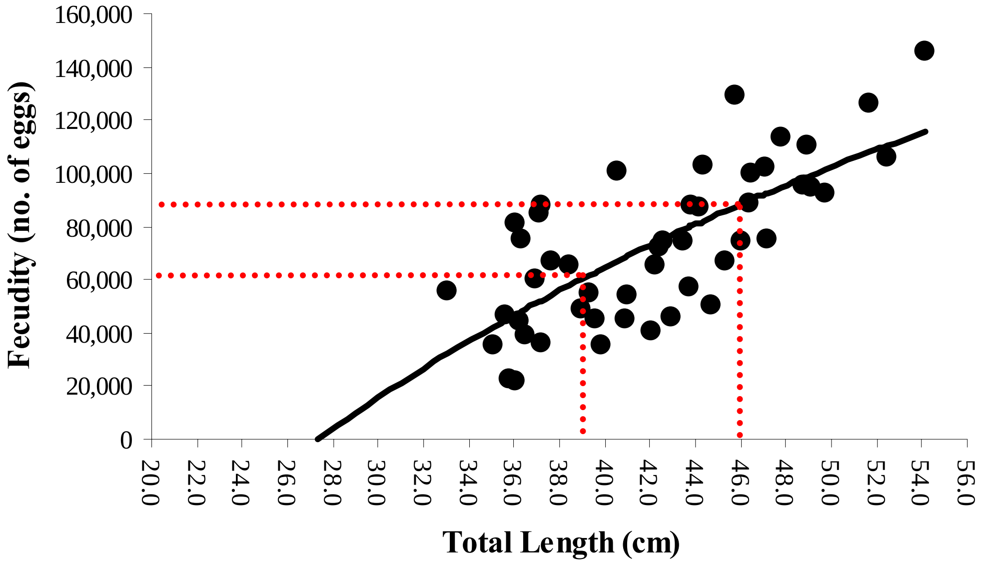


Figure 24 Length-fecundity relationship of shark catfish in term of logarithmic function.

The advantage of this function is that the model *per se* is basic and simple to use with any types of calculating apparatuses even though a scientific calculator. Additionally, it can be estimated the first size (or age) that female fish mature.

4. Length at 50% Maturity

The proportion of mature female (P_L) in each length class could not be calculated in this study. Two methods were proposed to estimate the length at 50% maturity as follows:

4.1 Mattson (1997) : From eq. (10) the estimated of L_m was 41.18 cm TL. This formula used M, L_∞ and K which were the population parameters of fish. The disadvantage of this method was the need of many population parameters. In some cases, these parameters cannot be achieved, either from lack of data or it is not include in the research objectives. Neither, it can estimate the effective size of a good mother of female.

4.2 Probability of fecundity: This study is used to estimate L_m by fitting a logistic function between proportion of cumulative fecundity frequency (P_{Fe}) and TL (Table 12). This method inspired from the probability of capture in trawl selection curve (Sparre and Venema, 1998).

A scattered plot from Figure 25 showed the logistic trend line. A nonlinear regression analysis was conducted by SPSS. The logistic function was:

$$P_{Fe} = \frac{\mathbf{1}}{\mathbf{1} + e^{(\mathbf{12.3975 - 0.3017}TL)}}\,; R^{\mathbf{2}} = \mathbf{0.9889}, S_{y.x} = \mathbf{0.0363}......................(\mathbf{34})$$

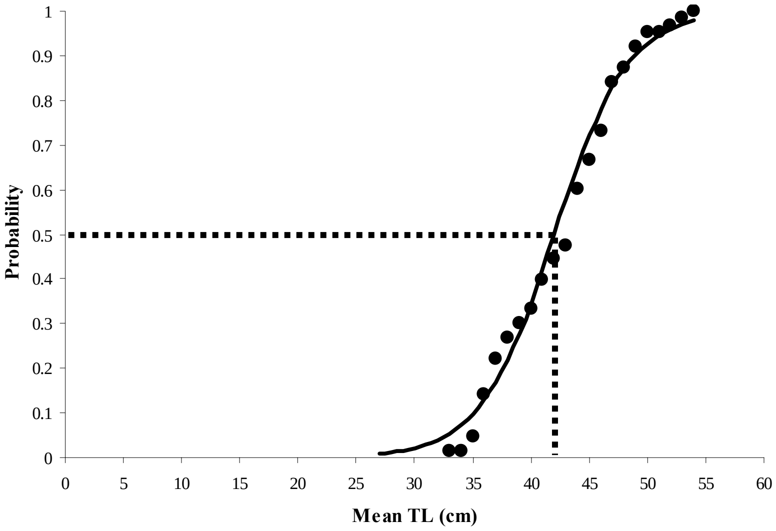


Figure 25 Probability of fecundity of shark catfish in the Mun River.

Table 12 Cumulative fecundity frequency of shark catfish.

TL (cm)	Fecundity Frequency	Cumulative Frequency	P_{Fe}
33.0	1	1	0.021
34.0	0	1	0.021
35.0	3	4	0.083
36.0	6	10	0.208
37.0	4	14	0.292
38.0	1	15	0.313
39.0	4	19	0.396
40.0	2	21	0.438
41.0	1	22	0.458
42.0	5	27	0.563
43.0	3	30	0.625
44.0	3	33	0.688
45.0	3	36	0.750
46.0	2	38	0.792
47.0	3	41	0.854
48.0	2	43	0.896
49.0	2	45	0.938
50.0	0	45	0.938
51.0	1	46	0.958
52.0	1	47	0.979
53.0	0	47	0.979
54.0	1	48	1.000

From eq. (34), the L_m was 42.01 cm whereas the effective range to be a good mother of shark catfish, estimated from eq. (12) and (14), was 38.56 – 45.46 cm which gives 60,173 and 88,180 eggs, respectively (Figure 24).

The probability of fecundity method developed in this study gave the similar L_m value as estimated from Mattson's (Mattson, 1997). The advantage from this method is that the estimation of the effective range to be a good mother. When the data cannot extrapolate P_L and impossible to estimate growth and mortality parameters, it cannot estimate the L_m from either logistic function or Mattson's method. This method will be a good application if the researcher has fecundity data. This partial method can also useful for aquaculturist to select the appropriate size of female broodstock in breeding.

5. Ovarian Histology

The ovarian histology was studied to confirm the spawning type of shark catfish. Three ovaries were sampled from female shark catfish during March – July 2005. The histological examination found three stages of oocyte with different degrees namely primary oocyte (po), early vitellogenic (ev) and vitellogenic stage (v) (Figure 26). In addition, post-vitellogenic follicle (pvf), atresia (at) and empty follicles (ef) were also found.

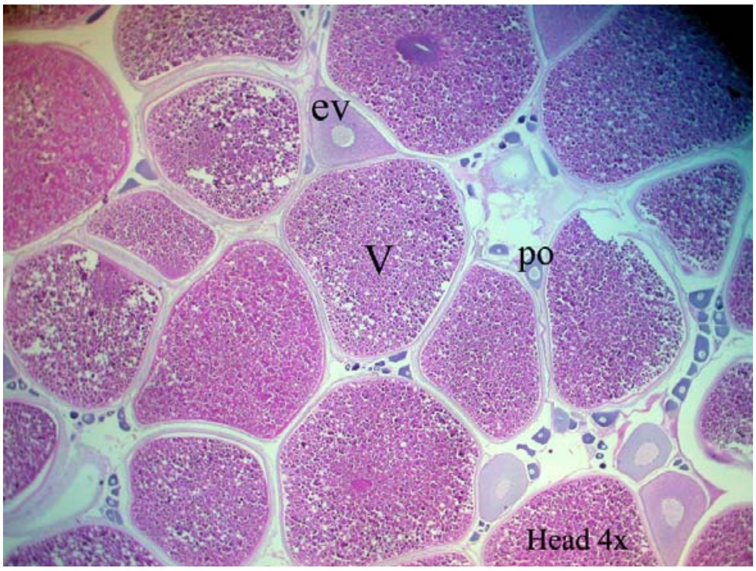


Figure 26 Ovarian tissue of shark catfish.
po = primary oocyte; ev = early vitellogenic stage;
v = vitellogenic stage

A primary oocyte is developed from oogonia. Oogonia are surrounded by ovigerous lamellae and become oocytes when meiosis begins. The transformation from oögonia to oocyte involves an increase in the size of the cell and nucleus (Grizzle and Rogers, 1976). For primary oöcyte stage, the ovarian lamellae contain few clusters of gonial cells and many enlarged follicles (van Eenennaam and Doroshov, 1998) (Figure 27).

An early vitellogenesis (ev) stage can be perceived by enlarged and thin vitelline envelope surrounded by a granulose cell layer. The oocyte cytoplasm contains small yolk globules. Clusters of gonial cells practically disappear at this stage. The oocyte is visible as small white spheres (van Eenennaam and Doroshov, 1998) (Figure 28).

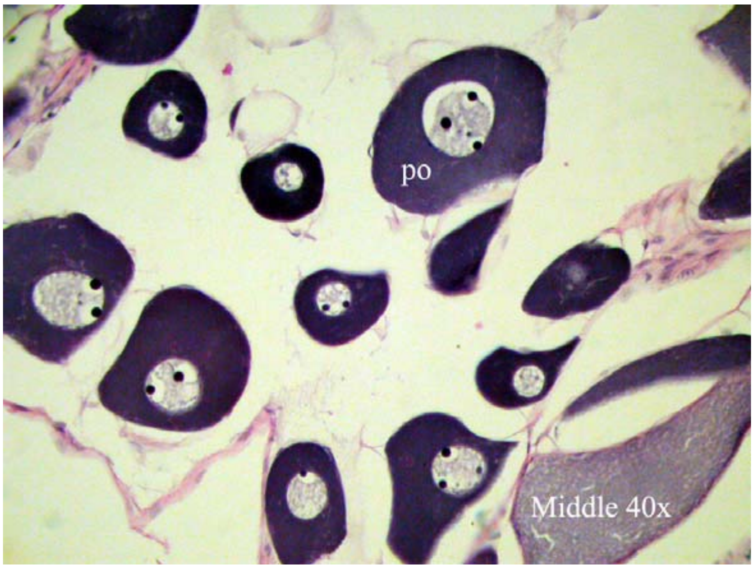


Figure 27 Ovarian tissue of shark catfish showing primary oocyte (po).

Figure 28 Ovarian tissue of shark catfish showing early vitellogenesis stage (ev).

Vitellogenesis stage (v) involves the breakdown of germinal vesicle and nuclear material is mixed with cytoplasm. Oocytes are ready to ovulate.

Post ovulatory stage which contained atresia in shark catfish ovarian tissue was also observed. Atretic follicles commonly found for a few weeks after spawning. The follicular cells enlarge and sometimes phagocytise the oocytes which are not spawned. The follicular cells of empty follicles in spent ovaries often enlarge, and the connective tissue surrounding the follicle thickens and becomes more vascular (Grizzle and Rogers, 1976) (Figure 29 and 30).

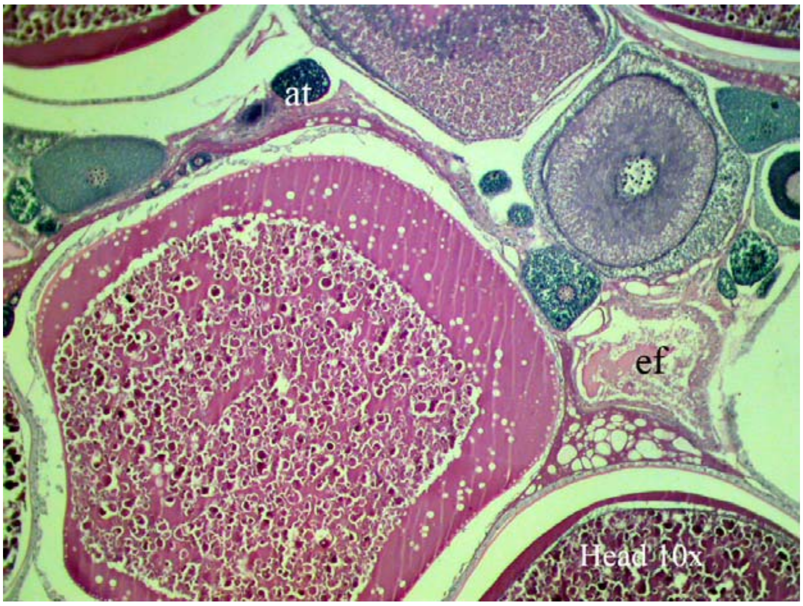


Figure 29 Ovarian tissue of shark catfish showing artesia (at) and empty follicle (ef).

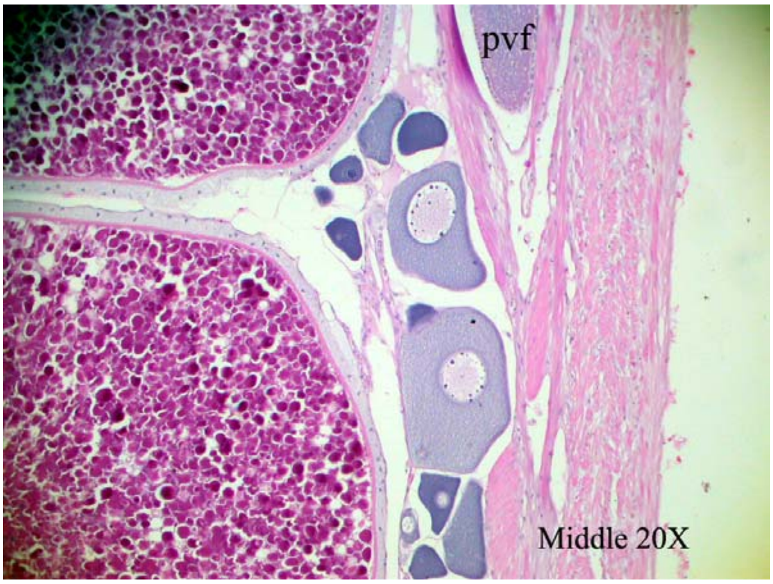


Figure 30 Ovarian tissue of shark catfish showing post-vitellogenic follicle (pvf).

Almost vitellogenesis stage was found in ovarian tissue of shark catfish with a few compositions of primary oocyte and early vitellogenic stage. It indicates that shark catfish is a group-synchronous species or partial spawner because ripe ovaries contain more than one distinct group or batch of oocytes and continuous developmental series of primary growth phase oocytes (Wright, 1992).

A study on ovarian histology can support the GSI values and fecundity profile that during the hitological sampling, March – July, is the spawning period of shark catfish. The largest size class of vitllogenic stage released during spawning season and the smaller ones released in subsequent year (Arockiaraj *et al.*, 2004). It is similar to Mekong giant catfish (MGC) that there are three stages of oocyte in the ovaries whereas the spawning season occurred in May (Manosroi *et al.*, 2003). Another bagrid catfish, *Mystus montanus*, also spawned once a year with the onset of north-east monsoon. But the gonadal maturation in morphologically and histologically could divide into five stages *viz.* immature, maturing, mature, matured and spent or rest (Arockiaraj *et al.*, 2004). It was seen that both MGC and bagrid catfish also be a group-synchronous spawner with one time spawning each year.

Post-vitellogenic follicle, atresia and empty follicle, an evidence of spent or released eggs, were found in a low scale. It means that the owner of ovaries used to spawn at least once in the former spawning season (Grizzle and Rogers, 1976). Hence, female shark catfish should spawn more than one time in a lifespan.

6. Sex Steroid Hormones Profile and Water Qualities

Three sex steroid hormones -- Testosterone, œstrogen and Progesterone -- were examined separately by up- and downstream areas for one year (Appendix Table 7). The pattern of the changes of these plasma levels in both down- and upstream were similar. After reaching a peak in April (T), May (17,20-P) and July (E_2), all three sex steroid levels tended to decreased (Figure 31).

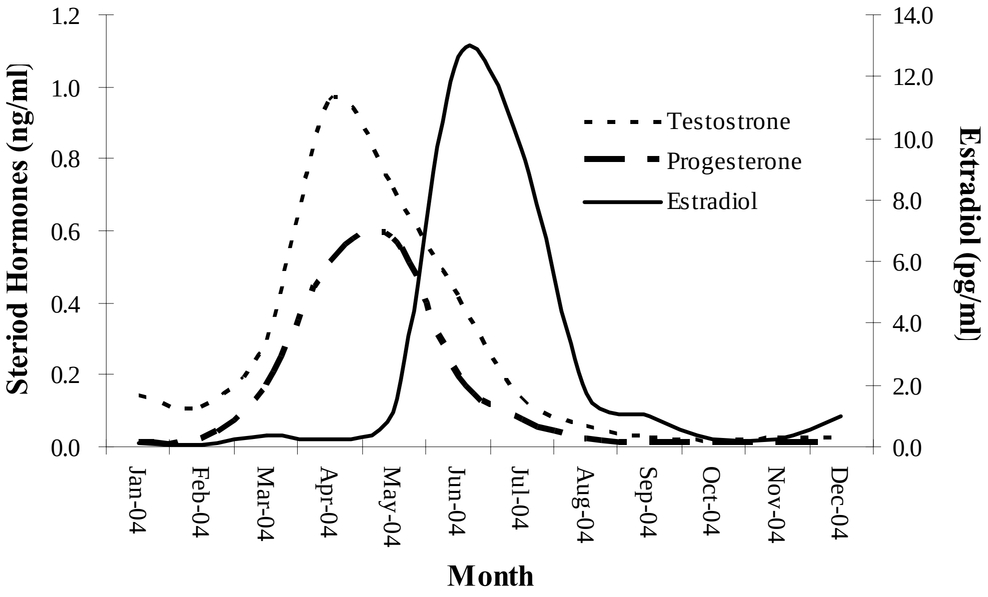


Figure 31 Sex steroid hormones profiles of shark catfish in the Mun River.

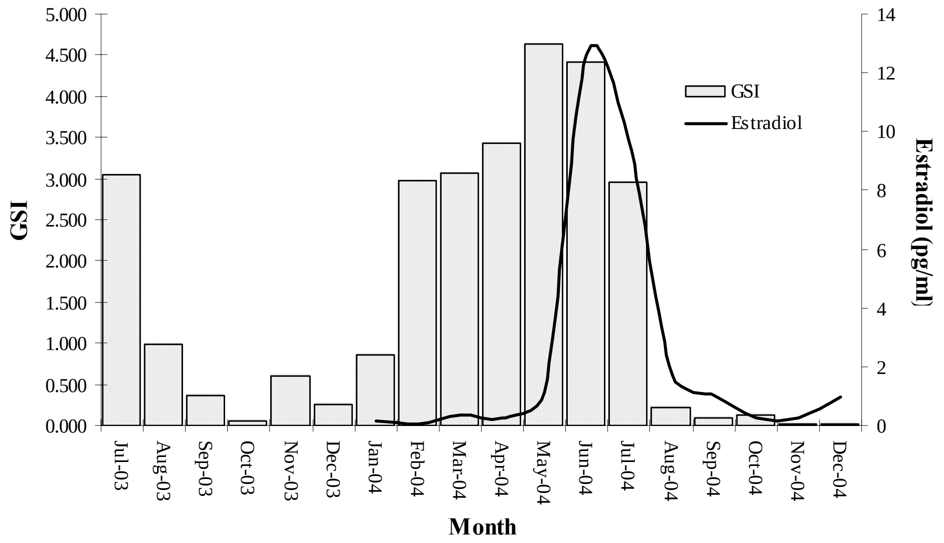


Figure 32 Changes of 17 β-œstradiol (E_2) compared to GSI.

High concentration of sex steroids could be detected during the rainy season, especially E_2, and consistent with the variation of GSI (Figure 32). The statistical analysis showed the temporal variation ($P<0.05$) but no spatial variation ($P>0.05$) for each sex steroid concentrations.

In many teleosts, T is a precursor of E_2 by aromatase converting process. Estrogen is released into the vascular system and stimulates the VTG synthesis in hepatic tissues (Janz, 2000). Plasma E_2 increases sharply at the beginning of vitellogenesis and then declines after spawning. Moreover, E_2 also stimulate the development of ovary and makes GSI increase. From this study, the peak of E_2 mainly started from June until July which was the spawning period of shark catfish. Similar to MGC, the peak of T and E_2 were also observed in May (Manosroi *et al.*, 2003).

This study also emphasised water qualities, rainfall and turbidity, and examined how related with reproductive activities of shark catfish. Eighteen consecutive months of sampled water were shown in Appendix Table 7. Temperature profile was stabled throughout the study whereas rainfall and turbidity fluctuated as shown in Figure 33. The relationship between rainfall and turbidity was explained in linear function as: (Figure 34)

$$Tb = \mathbf{3.674} + \mathbf{0.195}Rf\,;\,S_{y.x} = \mathbf{9.0899}, R^{\mathbf{2}} = \mathbf{0.823} \ldots\ldots\ldots\ldots\ldots\ldots.(\mathbf{30})$$

Univariate relationships between sex steroid hormones and water qualities revealed that, only E_2 has a relationship with rainfall and turbidity. The temperature, on the other hand, is in steady profile which may be affected by the time of sampling. Other two relationships could be explained in cubic functions as:

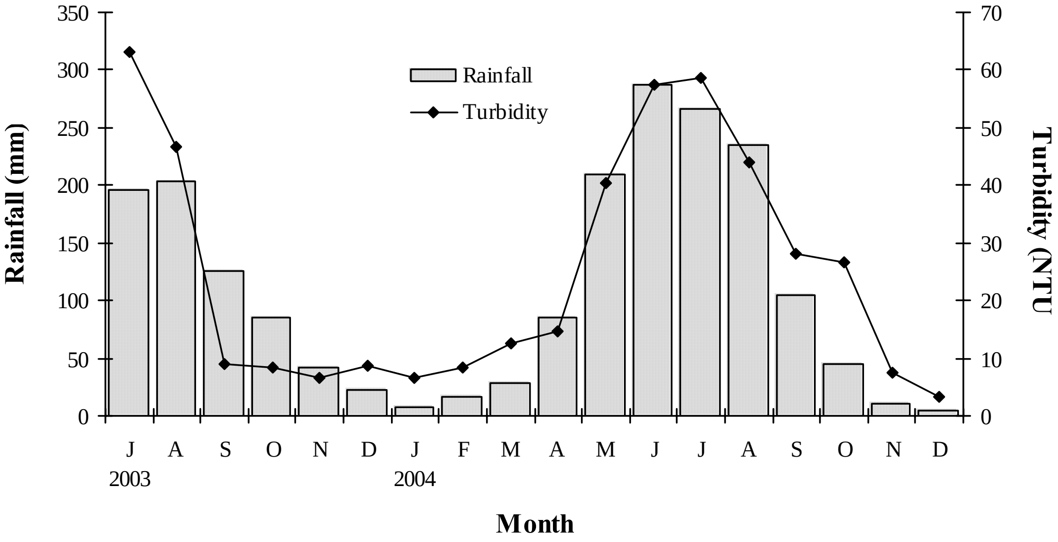


Figure 33 Profiles of rainfall and turbidity at the Mun River throughout the study.

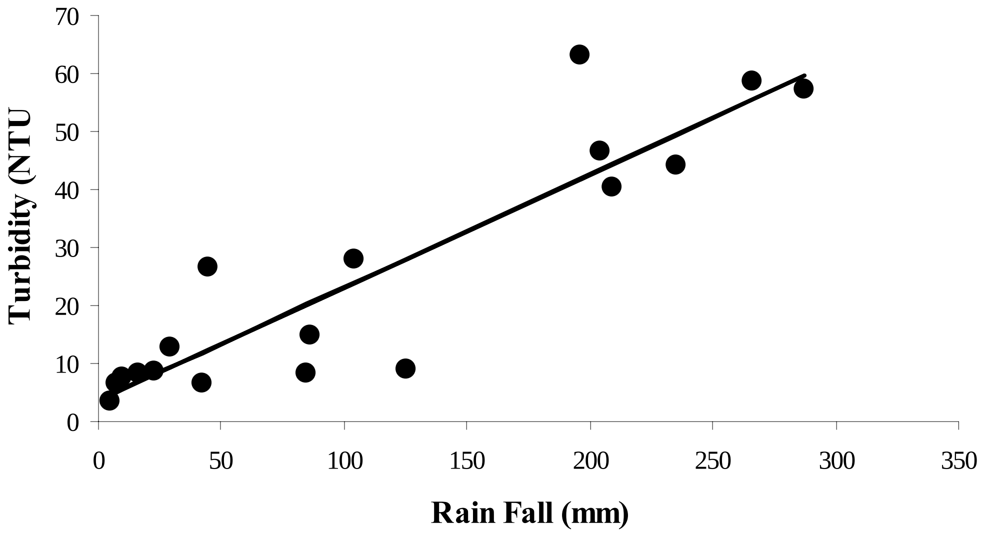


Figure 34 Relationship between rainfall and turbidity at the Mun River during the study period.

$$E_2 = \mathbf{0.0562}Rf - \mathbf{0.008}Rf^{\mathbf{2}} + \mathbf{2.6855} \times \mathbf{10}^{-\mathbf{6}} Rf^{\mathbf{3}} - \mathbf{0.2135}; S_{y.x} = \mathbf{0.9799}, R^{\mathbf{2}} = \mathbf{0.96} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{31})$$

and

$$E_2 = \mathbf{0.147}Tb - \mathbf{0.0104}Tb^{\mathbf{2}} + \mathbf{0.0002}Tb^{\mathbf{3}} - \mathbf{0.1222}; S_{y.x} = \mathbf{1.1885}, R^{\mathbf{2}} = \mathbf{0.9412} \ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{32})$$

which be shown in Figure 35 and 36, respectively.

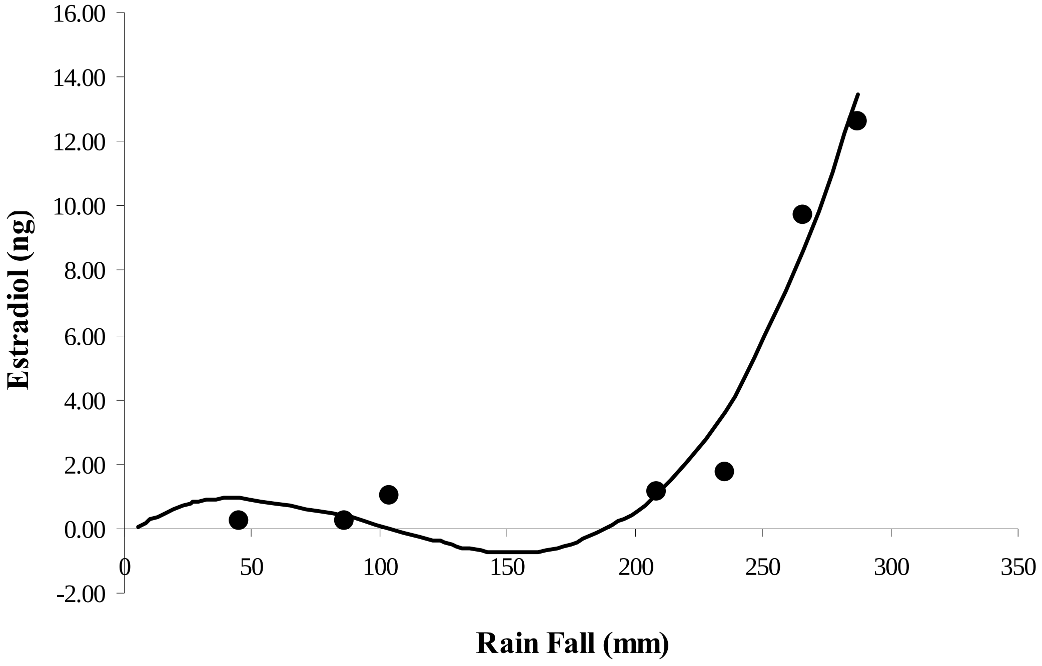


Figure 35 Univariate relationship between rainfall and E_2 of shark catfish in the Mun River.

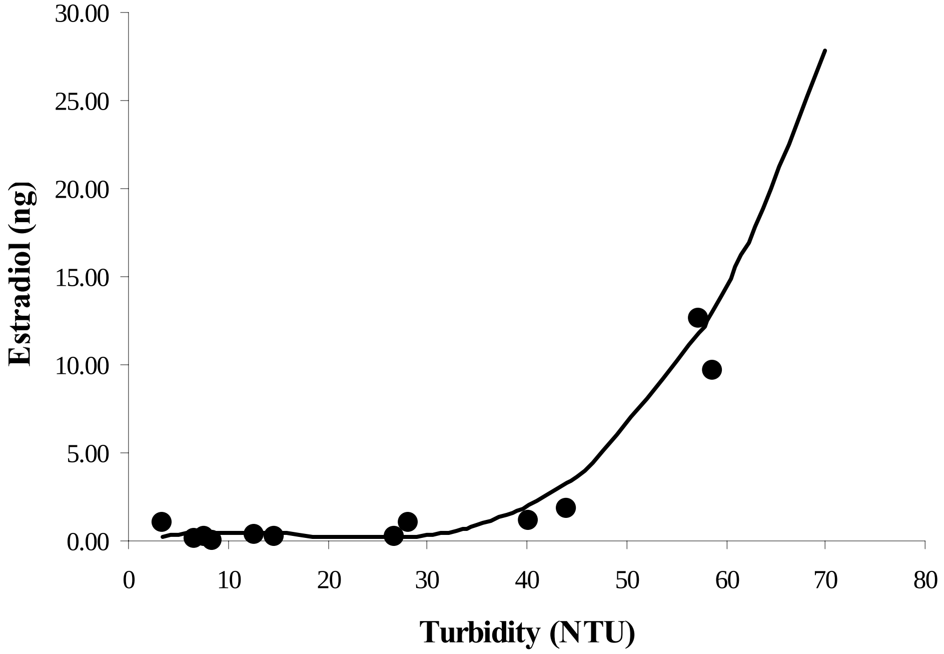


Figure 36 Univariate relationship between turbidity and E_2 of shark catfish in the Mun River.

It was shown that water qualities, especially temperature, rainfall and turbidity, were related to reproduction activities in tropical freshwater fishes (Gerking, 1980; Daye and Globe, 1984; Lowe-McConnell, 1987). As such Figure 37 and 38 showed the same trends between rainfall, turbidity and GSI. It was seen that GSI increased during the high levels of rainfall and turbidity. The increasing rainfall and turbidity may be the environmental signals for fish in activation of reproductive strategy.

Although there were the trend of multivariate relationship among water qualities and E_2, but it could not clearly conclude that both rainfall and turbidity were the stimulators for producing E_2. Because in natural condition, there are many factors that may affect to reproductive activity of fish such as age and condition factor of broodstock, food sources, spawning space (spaces competitor), or even predators (Lowe-McConnell, 1987; Wootton, 1992).

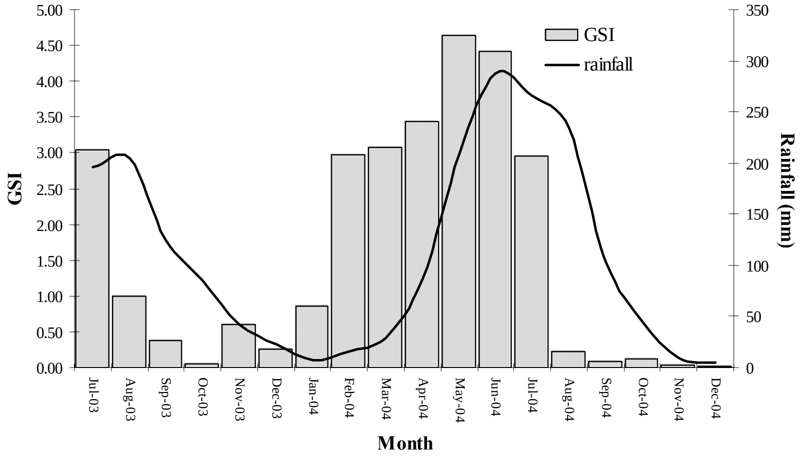


Figure 37 Trend of GSI of *H. waandersii* and rainfall in the Mun River.

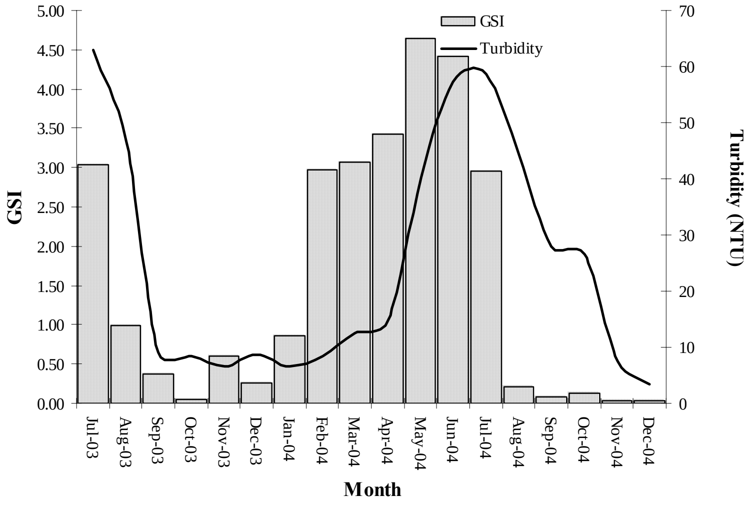


Figure 38 Trend of GSI of *H. waandersii* and turbidity in the Mun River

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7. Spawning Season

The monthly modes of egg stage, compared with up- and downstream areas, were shown in Table 13 and Figure 39. The egg stage followed by month in each station was expressed in Appendix Table 8 and Figure 40.

Table 13 Modes of egg stage.

Month	Mode of Egg Stage	
	Upstream	Downstream
Jul-03	4	5
Aug-03	1	1
Sep-03	1	1
Oct-03	1	1
Nov-03	1	1
Dec-03	n.d.	2
Jan-04	1	2
Feb-04	n.d.	2
Mar-04	n.d.	2
Apr-04	n.d.	4
May-04	5	5
Jun-04	5	5
Jul-04	5	5
Aug-04	1	1
Sep-04	1	1
Oct-04	1	1
Nov-04	1	1
Dec-04	n.d.	1

n.d. = no data

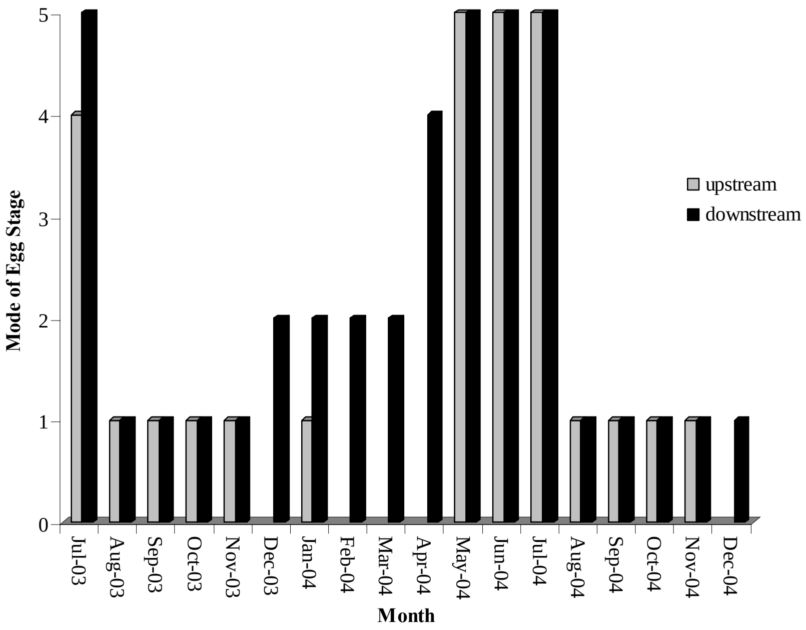
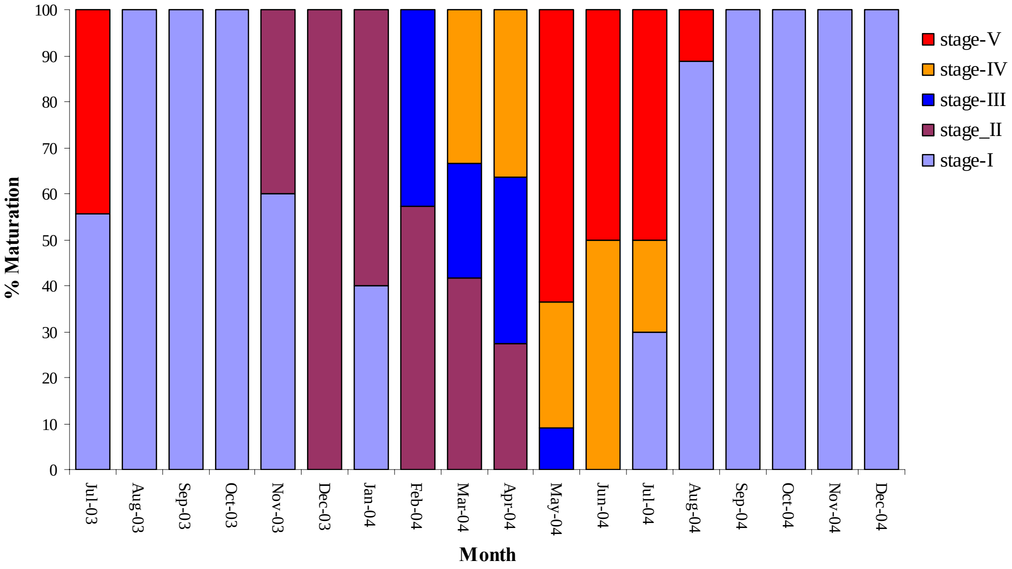


Figure 39 Monthly modes of egg stage of *H. waandersii* compared with up- and downstream areas in the Mun River.

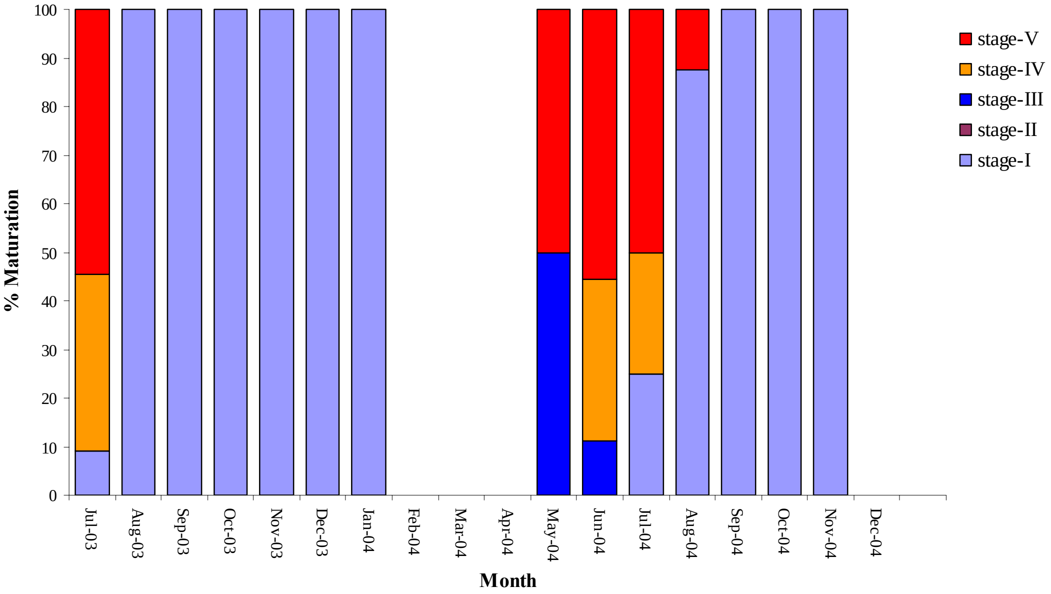
Few samples were caught from November to April in the upstream area and stage- V ovaries were found in the both areas (Table 11). Although it was found some samples in January at Khong Jiam Station but the samples were in immature stage (Figure 40 a and b). During May through July, however, samples could be caught both up- and downstream areas with mature ovaries. While in August, only stage-I fishes could be caught in both areas.

In August to September, small sized females with stage-I ovaries were caught both in up- and downstream areas. A volume of catch moved orderly month by month from upstream to downstream area. In December, a few shark catfish with undeveloped gonad was found only in Khong Jiam.

All pangasiids are known as migratory species with diverse patterns. In the Mekong mainstream, shark catfish showed relatively short upstream migration during the late dry season and/or early flood season (Poulsen and Jørgensen, 2000).
The purposes of movement are both spawning and feeding migrations and some of the migrants move into major tributaries such as Nam Ngum, Mun and Songkhram Rivers. In addition, an early dry season feeding migration has also been observed (Warren *et al.*, 1998).



a. downstream stations



b. upstream stations

Figure 40 Monthly egg stage of *H. waandersii* in each sampling station.

It could congregate from all aspects of the studies on reproductive biology that, shark catfish reproduces once in a year and has a short spawning season during the rainy season. Shark catfish moves upstream from the Mekong River since January with stage-I and stage-II ovaries. Then the ovary is developed to stage-III – stage-V in the Mun River and spawn during May through July. The occurrences of mature/spent fishes and the profiles of sex steroid hormones in both up- and downstream areas implied that shark catfish need not move upstream too far to spawn. As all pangasiids species are rapids-dependent (Amornsakchai *et al.*, 2000); shark catfish could spawn in both up- and downstream rapids. All rapids, where fast flowing and oxygenated, are the ideal spawning grounds for many fishes in the rainy season (Viravong *et al.*, 2005). In addition, shark catfish was reported to inhabit in deep pools, which located near the rapids, during the dry season (MRC, 2002). Therefore, the spawning area of shark catfish should be covered from Kang Sapue to Kang Tana because of a lot of rapids and the demersal-adhesive eggs of shark catfish can be found (Riparian fishermen, *pers. comm.*).

For the longer distance movement, the purpose movement of shark catfish relates to feeding more than spawning. Catch of shark catfish at the upstream area was higher during the rainy season and coincided with the highest peak of bivalves, *Corbicularia* sp., which was the main food item found in the stomach of shark catfish (Payooha *et al.*, 2004). This concurred with the finding of Viravong *et al.* (2005). They reported that after fish had reproduced in the deep pools, it moved to floodplain feeding ground and joined sub-adults (Poulsen and Jørgensen, 2000). Rainboth (1996) also mentioned that shark catfish moved downstream, from the flood forests, when water clears at the end of the flood season. Therefore, the absence of samples in the upstream area after the closing of sluice gates implied that fish already migrated back to the deep pools in the Mekong mainstream.

Fisheries

1. Relative Yield per Recruit and Average Biomass per Recruit

The relative yield per recruit and average biomass per recruit was shown in Table 14 and Figure 42. The input parameters for FiSAT sub-routine were 28.88 cm (TL) of average L_c from gillnet and hook; and 59.74 cm (TL) for L_∞, respectively. The ratio of M/K was 1.3525 per year.

Table 14 Relative yield per recruit and average biomass per recruit of shark catfish.

E	$(Y/R)'$	$\bar{B}/R$	**E**	$(Y/R)'$	$\bar{B}/R$
0.01	0.015	0.849	0.6	0.057	0.24
0.2	0.028	0.706	0.7	0.058	0.157
0.3	0.039	0.572	0.8	0.056	0.088
0.4	0.048	0.449	0.9	0.052	0.036
0.5	0.054	0.338	0.99	0.047	0.003

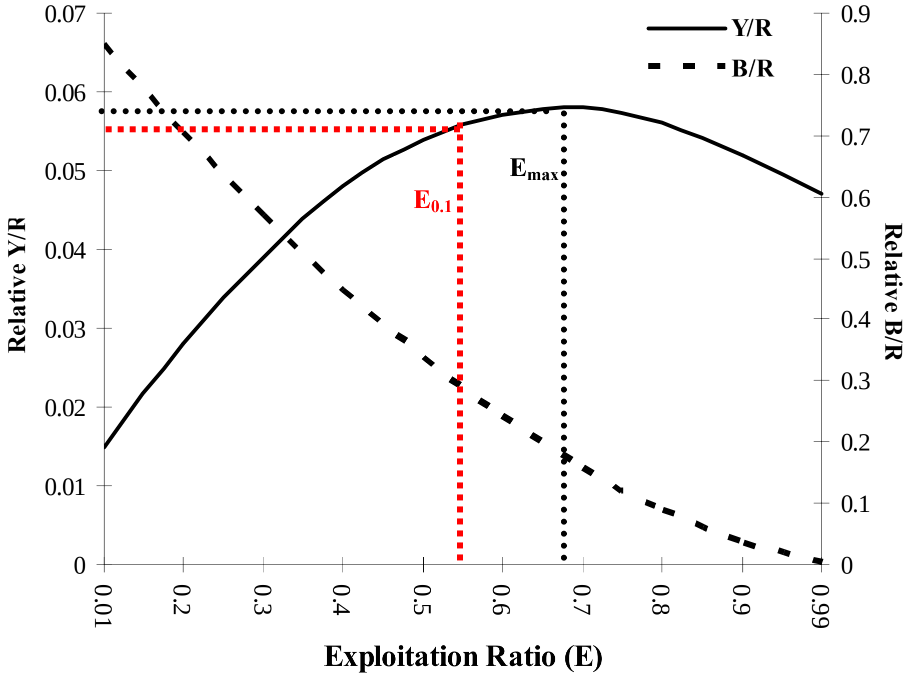


Figure 42 Relative yield per recruit and average biomass per recruit of shark catfish in the Mun River.

Table 15 Maximum E and $E_{0.1}$ of *H. waandersii* in the Mun River, derived from relative yield per recruit model.

Sources	E	F $(year)^{-1}$
From mortality study	0.633	3.077
$E_{0.1}$ (MSE)	0.553	2.689
E_{max} (MSY)	0.679	3.302

A knife-edge relative yield per recruit curve (Figure 42) reveals that relative yield per recruit increased as the E increased until it reached the apex point. Then it slightly decreased after increasing of E. According to high M-value in this study (1.7853 per year), it is noted that at the first phase, relative yield per recruit was varied along with E. Then relative yield per recruit was slightly changed after it reached the apex point. The curve has the E_{max} which gives the Maximum Sustainable yield (MSY) at 0.679 while the E value from mortality study is 0.633 (Table 15). The $E_{0.1}$, which is the Maximum Sustainable Economic Yield (MSE), is 0.553. The E_{max}, however, ignores the effect of fishing on future generations (Sissenwine and Shepard, 1987). It is therefore Gulland and Boerma (1973) and Deriso (1987) applied the $E_{0.1}$ value to estimate the desirable value. This point is defined as the E at which the slope of a line tangential to the relative yield per recruit curves at the one-tenth of its slope origin (Gulland and Boerma, 1973). The $E_{0.1}$ measure is a sense of bioeconomic criterion that is a marginal yield of less than 10%. It is closed to the point at which most fisheries administrators would consider further to optimise the exploitation rate for economically worthwhile (Caddy and Mahon, 1995). Deriso (1987) stated that $E_{0.1}$ is desirable because it is lower than E_{max} and avoids the growth overfishing but does not reduce the yield to any great extent and does not has a severe reduction of the spawning biomass.

It is indicated that the exploitation rate of shark catfish in the Mun River is nearly reaches the MSY but over the MSE. All the E values, E_{max}, E and $E_{0.1}$, are 18% and 13% and 0.05% greater than the optimum exploitation ratio (E_{opt} = 0.5) which is the level that fish is utilised and does not effect to the stock size, respectively. For the maximum profit management of shark catfish fisheries in the Mun River, it should reduce the exploitation ratio down to 8% at MSE level. At this point, it will closely exploit at the E_{opt} and will not destroy the stock biomass.

Average biomass per recruit model expresses the annual average biomass of survivors as a function of fishing mortality (Sparre and Venema, 1998). The average biomass per recruit values related to the relative yield per recruit values. In the case of F is nearly zero; the value of average biomass per recruit, or ‘virgin biomass per recruit’($^{Bv}/_{R}$), is the biomass of unexploited stock. Therefore, from this study, shark catfish in the Mun River had a virgin biomass per recruit = 0.849.

2. <u>Stock Size</u>

An estimation of stock size, using length-based cohort analysis which modified by Sommani (1987), was shown in Table 14 and Figure 43. The relationship between fishing mortality and length class, using negative John-Schumacher function as applied by Sommani (1988), was expressed in Figure 44.

The class length of LFD was regrouped according to the nature of fish growth which based on the assumption of a constant parameter system (Sommani, 1987; Sparre and Venema, 1998). Official records of inland capture fisheries statistics in Thailand are extensive and insufficient and the Mun River is not the exception. Hence, the LFD in this study had to sample as many methods as possible for making sure that it would be represented, or at least in a proportion, to those of the total landings. Then the estimation should closely to the true population sizes or at least could be used as the indices for them.

From Table 16, it could be said that the recruitment of shark catfish was approximately 7,745 fishes. The stock size in the Mun River is about 40,598 fishes in the natural habitat.

Table 16 Fishing mortality coefficient (F_i), expected number in the sea (N_i), and number of survivor of shark catfish.

Lower TL (cm)	**Average Catch**	**F_i/ month**	**Calculated Number in the Sea**	**Number of Survivor**
5	11.5	0.00301	7,745	7,733
8	71.5	0.01920	7,176	7,104
11	143	0.04000	6,534	6,391
14	237.5	0.07086	5,811	5,574
17	517.5	0.17100	5,075	4,558
20	618	0.24094	4,118	3,500
23	803	0.40967	3,118	2,315
26	497.5	0.35709	2,023	1,526
29	433	0.46147	1,318	885
32	251	0.43068	746	495
35	107.5	0.28630	408	301
38	102.5	0.45313	245	142
41	48.5	0.43042	109	60
44	30.5	0.79152	43	13
47	4.5	**0.25648***	7	3
Total	3,877		44,475	40,598

* terminal F per month from mortality study

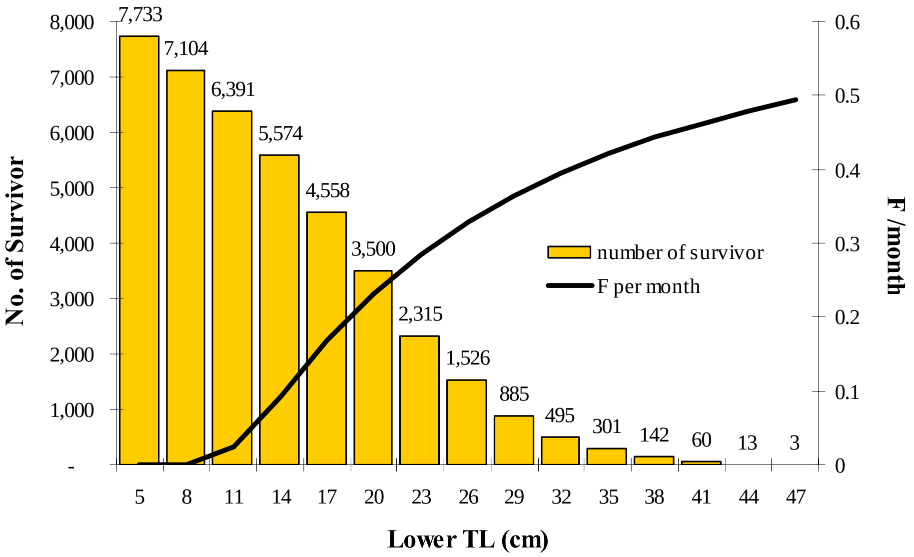


Figure 43 Virtual Population Analysis (VPA) and F at each length class of shark catfish in the Mun River by length-based cohort analysis.

The data from Table 14 revealed that F tended to regressive increase as the size increased. Under the negative Johnson-Schumacher's function which modified by sommani (1988), the constants were estimated by regression analysis between $ln(F_i)$ and $\frac{\mathbf{1}}{(L_i - L_{\mathbf{0}})}$ where L_0 was 3.5 cm. Then all constants were used as input parameters in nonlinear regression analysis by SPSS. The iteration will stop when the difference between successive parameters estimates was less than 10^{-8}.

The relationship of F at each length class, Figure 44, was expressed as:

$$F_i = \mathbf{0.7199}e^{-\frac{\mathbf{15.278}}{(L-\mathbf{6.54})}}; S_{y.x} = \mathbf{0.1286}, R^{\mathbf{2}} = \mathbf{0.6447} \text{....................} (\mathbf{33})$$

From eq. (33), the highest possible F was reached when shark catfish attained its L_∞ (59.74 cm). In this case, F_{max} was 0.5402 per month or 6.4824 per year. Thus, the maximum Z would be 0.689 per month or 8.2677 per year, respectively.

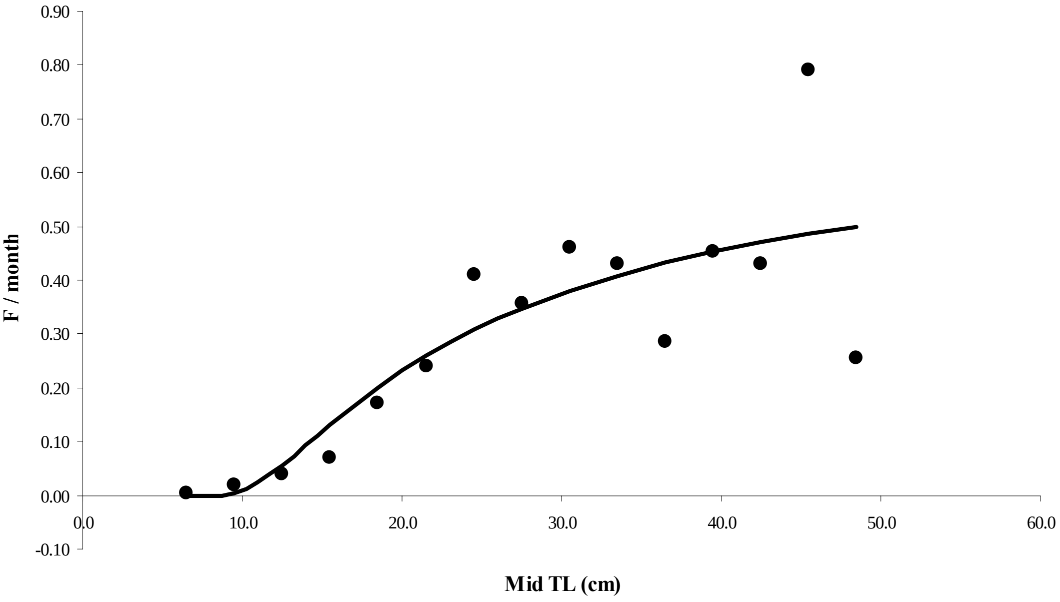


Figure 44 The relationship between F and length class of shark catfish in the Mun River.

3. Gillnet Selectivity and Optimum Length for being Caught

The total number of shark catfish, with the size ranged from 13.0 – 49.0 cm TL, was 1,756 fishes (Appendix Table 9). Size frequency distribution, 14.0-36.0 cm for 4.5 cm mesh, 14.0-44.0 cm for 5.5 cm mesh, and 15.0-49.0 cm for 6.5 cm, was shown in Figure 45.

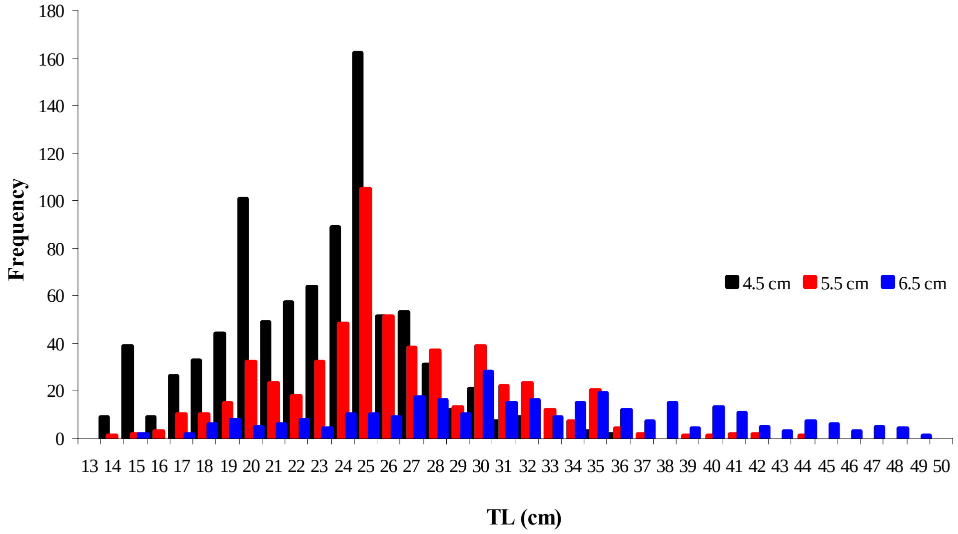


Figure 45 Frequency distribution of shark catfish caught by three mesh sizes gillnets in the Mun River.

The result shows multimodal distribution with overlapping fish size range among three mesh sizes. When changing the data into probability, it can be separated in three groups. Therefore, shark catfish was caught by three different processes; entangled, snagged and wedged, followed by the report of Hovgård and Lassen (2000). Theoretically, the data should be split and estimated independently. Practically, however, the estimator has to be assumed that the selectivity curve is unimodal since it is impossible to collect the data separated by the type of catching process in the field (Hamley and Regier, 1973). As this study focuses on the length of shark catfish as a multi-meshes of gillnet fisheries management based on maturity size, so that the type of catching process is not concerned.

Optimum length for being caught, estimated from the various mesh sizes model, is shown in Table 17. Selection factors are expressed in Table 18. Single mesh and multi-meshes selectivity curves are shown in Figure 46 and 47, respectively.

It was seen by means of single mesh that L_c was increased by mesh size. In terms of multi-meshes size, the L_c was reduced to 29.56 cm since the mesh of 4.5 and 5.5 cm caught the small fish, which was the majority in catch composition. To let the fish had an opportunity for reproduction, at least once before being caught, the L_m was used as a criterion for deciding an optimum mesh size.

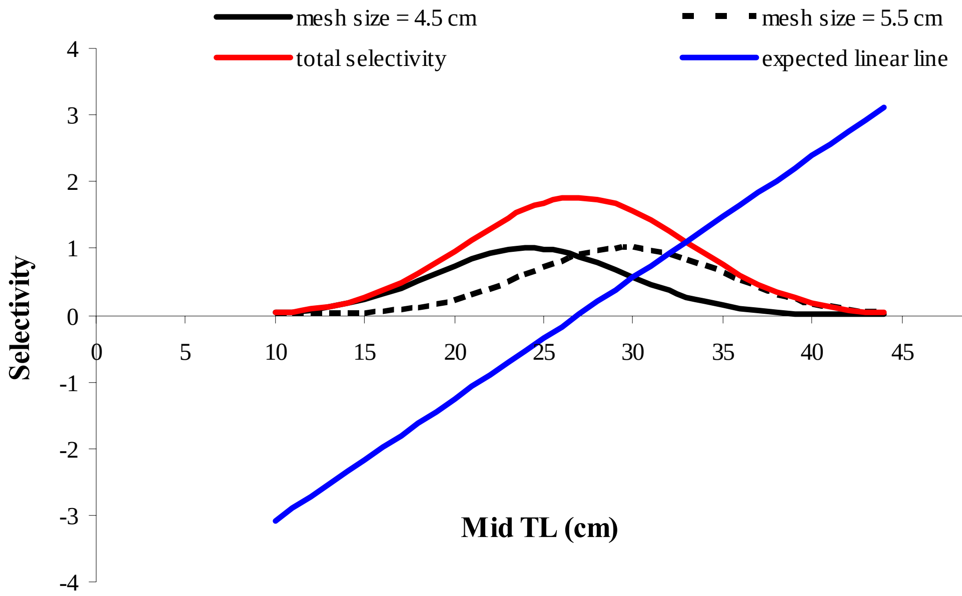
Table 17 Optimum length for being caught (L_c), estimated from various mesh sizes model, compared with L_m.

Mesh (cm)	Status	L_c (cm)
4.5	Single mesh	23.33
5.5	Single mesh	28.52
6.5	Single mesh	33.71
4.5 and 5.5	Represent for two meshes	26.92
5.5 and 6.5	Represent for two meshes	30.29
4.5, 5.5 and 6.5	Multi-meshes	29.56
Maturity		**Length (cm)**
Length at first maturity		27.36
Length at 50% maturity from Mattson (1997)		43.18
Effective Ranged for shark catfish's female broodstock		38.56 – 45.46
Length at 50% maturity from this study		42.01

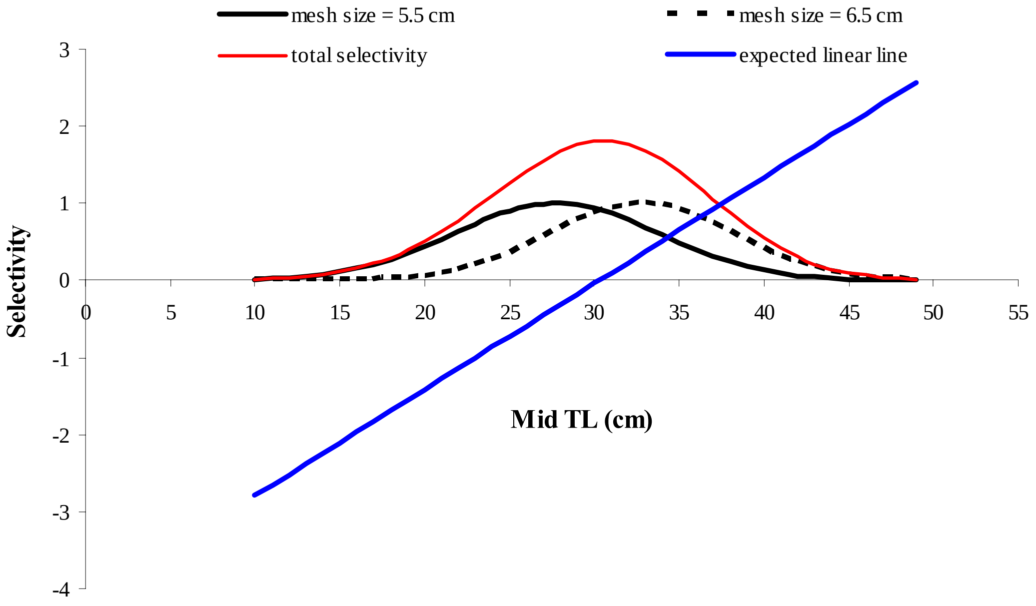
Table 18 Selection Factors from the study (Holt, 1963).

Mesh (cm)	SF
4.5 and 5.5	5.3839
5.5 and 6.5	5.0476
Common SF from various mesh sizes model	5.1854
Overall SF from multi meshes	5.3744

All of the L_c values, as shown in Table 15, were less than L_m and the effective range for female's broodstock. If the length at first maturity (27.36 cm) was considered, the fishermen can use gillnet at the mesh size over 5.5 cm. Nonetheless, the female fish at the size less than 38.56 cm – a lower limit to be a 'good' mother – the quantity and quality of eggs as well as maternal condition is not good enough to give strong quality of the recruitment. It was said straightforwardly that all meshes destroy the parental stock. In fact, local fishermen use to fish with all of such meshes throughout the year alternately by season, area, and fish size. In addition, gillnet is a flexible fishing gear for multi-species. The management regime should be optimized for reducing any controversies between government and local fishermen in gillnet operation.



a.



b.

Figure 46 Single mesh selectivity curve of shark catfish gillnetting in the Mun River. The X-intercept of the linear line is the optimum length for being caught.

a. 4.5 vs. 5.5 cm mesh and
b. 5.5 vs. 6.5 cm mesh.

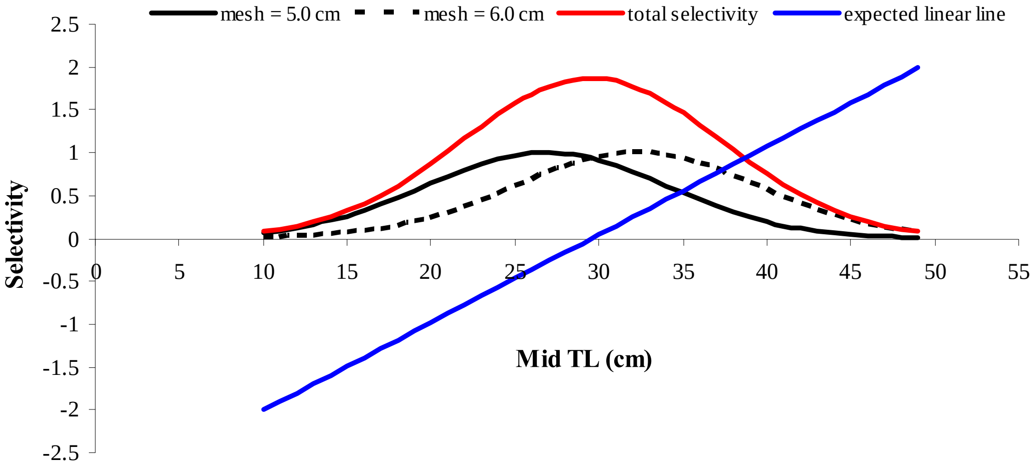


Figure 47 Multi-meshes selectivity curve of shark catfish gillnetting in the Mun River. The X-intercept of the linear line is the optimum length for being caught (29.56 cm).

Ideally, optimum mesh size, estimating from overall selection factor (5.3744), for female shark catfish should be up to 7.0 cm. But for the holistic viewpoint of multi-meshes/multi-species of gillnet, the 5.5 cm mesh is a compromised mesh size for shark catfish fisheries. This mesh size can prevent the incident of 'growth overfishing' from small-meshed gillnets (Amarasinghe, 1988).

4. Hook Selectivity and Optimum Length for being Caught

Two sizes of bottom long line hook, no. 17 and 18, were used altogether. The average width of them was 6.25 mm (Jutagate and Mattson, 2003). The total number of shark catfish, ranged from 14.0 – 48.0 cm (TL), was 116 fishes (Appendix Table 10).

4.1 Probit analysis: The L_c was calculated by substituting the probit value of five. The length, which ranged from $L_c \pm$ s.d. is called 'selection range' for probit method. A belled-shape selectivity curve is shown in Figure 48.

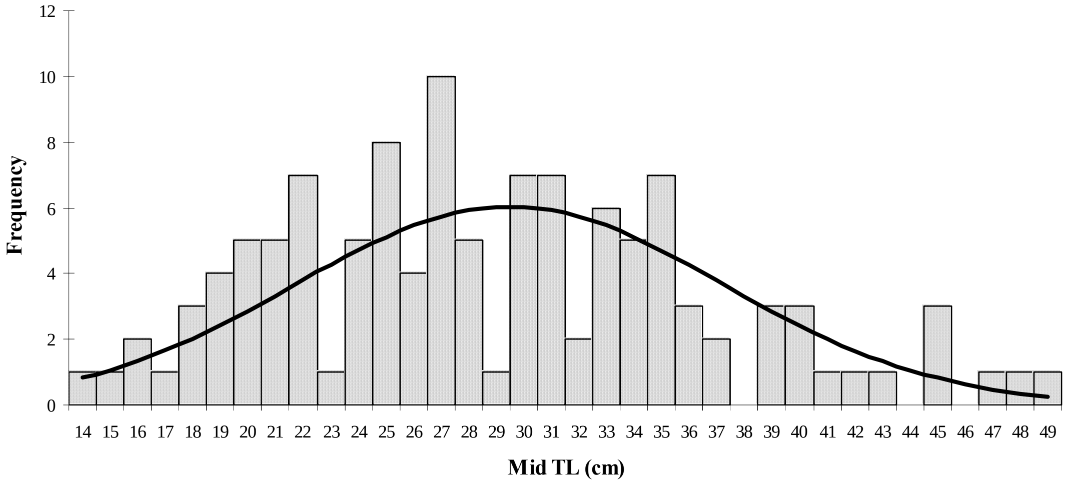


Figure 48 Selectivity curve of bottom longline of *H. waandersi* fishery in the Mun River using probit analysis.

4.2 Probability of capture: The L_c was estimated by fitting a logistic function by the method of probability of capture in trawl selection curve as the same process of the estimation of L_m (Sparre and Venema, 1998).

The length, which ranged from 25% to 75% of probability of capture, is symmetrical around 50% is called ‘selection range’. Therefore, the length at 50% is L_c, respectively.

An S-shape selectivity curve is shown in Figure 49. Constants of logistic function were firstly estimated from regression analysis. Then they were used as the input estimators for nonlinear regression by SPSS. The logistic function of hook selectivity was expressed as:

$$P_L = \frac{\mathbf{1}}{\mathbf{1} + e^{\mathbf{6.0146 - 0.2146}L}} ; S_{y.x} = \mathbf{0.2175}, R^{\mathbf{2}} = \mathbf{0.9963} \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{34})$$

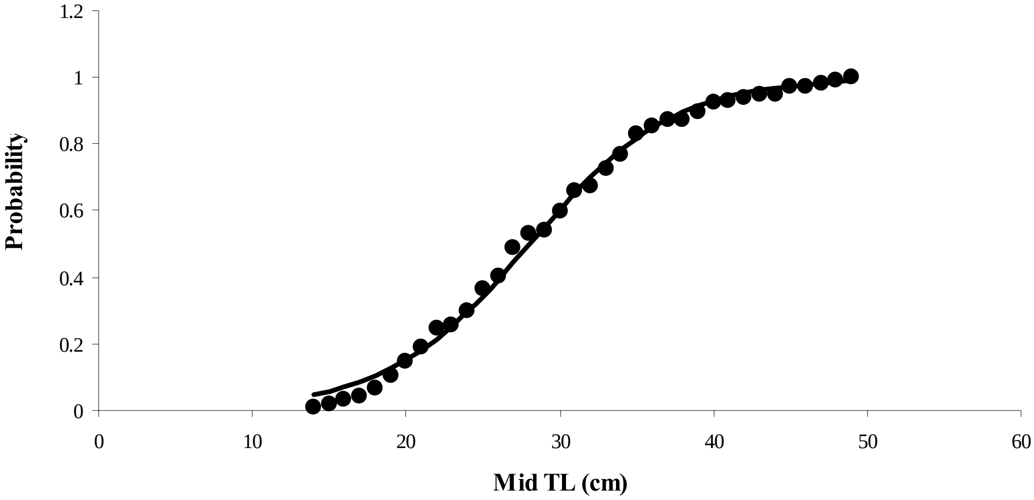


Figure 49 Selectivity curve of bottom longline hook using probability of capture.

All of the L_c values, as shown in Table 19, were less than L_m and the effective range for female's broodstock. If the length at first maturity (27.36 cm) was focused, hook no. 17 and 18 could be used altogether.

Table 19 Optimum length for being caught (L_c) of *H. waandersii* in the Mun River, estimated from probit analysis and probability of capture, compared with L_m.

Method	**Selection Range**	**L_c (cm)**
Probit analysis	$21.25 \le L_c \le 36.74$	28.99
Probability of capture	$22.67 \le L_c \le 33.54$	28.10
Maturity		**Length (cm)**
Length at first maturity		27.36
Length at 50% maturity from Mattson (1997)		43.18
Effective Ranged for shark catfish's female broodstock		38.56 – 45.46
Length at 50% maturity from this study		42.01

If selection factor, $SF = \frac{L_c}{hooksize}$, was considered; SF of average hook size in this study (6.25 mm) was 44.96. Then, if fishermen want to catch the shark catfish at L_m, they have to increase the hook size to 9.6 mm or < no. 14 (Jutagate and Mattson, 2003).

The result from both methods revealed that, there were not different of L_c values (P>0.05). However, the probability of capture method is popularly used amongst fishery biologists. Thus, it is recommended for applying this method in estimation of longline hook selectivity function.

Table 20 The L_c values from gillnet and longline and relative yield per recruit.

Mesh (cm)	**L_c (cm)**	$\left(Y/R\right)'$
Maximum $\left(Y/R\right)'$		0.058
Gillnet (multi-meshes)	29.56	0.059
Longline (average)	28.55	0.058

The L_c values from gillnet and longline quite similar and give the closely values of maximum relative yield per recruit (Table 20). It is therefore the fishery status of shark catfish in the Mun River is presently reach the maximum use and should concern about the management of this species.

In the inland fisheries of Thailand, according to the DoF, the closed season is enforced during 16th May to 15th September. It is mostly coincided with freshwater fish spawning season. Gillnet and bottom longline are prohibited to operate whereas hand hook, scoop net (size > 2x2 m^2) and traps are allowed (Jutagate and Mattson, 2003). For the ‘win-win solution’ management regime on shark catfish broodstock, fishermen should use of > 5.5 cm gillnet and hook size at < no. 17 in the open water zone apart from the spawning and nursing ground along the Mun River which covered from Kang Tana rapids through Kang Sapue rapids and aware the floodplain in Sawang Weerawong District as a nursery protected area in the closed season.

CONCLUSION

Shark catfish was a group-synchronous spawner with a short spawning season and spawns at least two times in the lifespan. The average fecundity was 85,174±43,206 eggs. The size that female fish mature was 27.36 cm. The size at 50% maturity was 42.01 cm while the effective size range to be a good spawner was 38.56-45.46 cm.

A short spawning season is occurred during the rainy season. Shark catfish started moving from the Mekong mainstream since January with stage-I ovary. It developed the eggs in the Mun River and spawned during May through July. The spawning ground was rapids in the Mun River which covered Kang Tana through Kang Sapue. After spawning, parental stock moved back to deep pools in the Mekong mainstream whereas the juvenile moved farther to the floodplain at Sawang Weerawong District for nursing and feeding purposes. Then it moved backward and joined with adult stock in September.

Shark catfish was an isometric growth pattern fish with non-seasonal growth curve. The growth parameters are; L_∞ = 59.74 cm, K = 1.32 per year and W_∞= 1,415.2 g. The lifespan, or longevity, varied from about two years and four months to three years. The recruitment pattern was prolonging period with a prominent peak during March to August.

The mortality coefficients of shark catfish were Z=4.863, M=1.7853 and F=3.078 per year, respectively. It has been exploited about 60% of total mortality. The exploitation rate of shark catfish in the Mun River was nearly reaches the MSY but over the MSE. The E values, E_{max}, E and $E_{0.1}$, were 18% and 13% and 0.05% greater than the optimum exploitation ratio (E_{opt} = 0.5), respectively. For the maximum profit management of shark catfish fisheries in the Mun River, it should reduce the exploitation ratio down to 8% at MSE level. At this point, it would closely exploit at the E_{opt} and would not destroy the stock biomass.

In fisheries aspect, the utilisation of shark catfish resource in the Mun River was nearly reaches the maximum relative yield per recruit. It should strongly concerns in growth overfishing situation. The optimum length for being caught (L_c) of tradition fishing gears, gillnets and bottom longlines, are 29.56 cm and 28.55 cm, respectively.

The benefit on management of Pak Mun Dam sluice gates is impacted on shark catfish in terms of feeding more than spawning purpose. During the closed season, 16th May to 15th September, fishermen should use of the greater mesh size than 5.5 cm gillnet and the lesser hook size than no. 17 in the open water zone apart from the spawning and nursing ground along the Mun River which covered from Kang Tana rapids through Kang Sapue rapids and aware the floodplain in Sawang Weerawong District as a nursery protected areas.

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APPENDIX

Appendix Table 1 Length-weight data.

TL (cm)	W (g)	TL (cm)	W (g)	TL (cm)	W (g)
3.1	0.7	16.0	28.3	43.5	568.0
6.5	2.4	17.2	25.1	43.7	580.0
8.3	3.9	18.5	29.3	43.8	585.0
8.5	4.0	18.5	32.8	43.8	692.0
8.5	4.0	18.8	32.7	44.2	600.0
8.6	3.8	19.4	39.9	44.4	610.0
9.4	4.1	19.5	42.8	44.7	625.0
9.4	5.4	19.7	45.2	45.2	584.0
9.4	6.7	20.2	62.0	45.3	657.0
9.6	5.2	20.4	48.0	45.7	680.0
9.7	4.5	21.2	48.6	46.0	819.0
9.7	5.7	21.4	52.3	46.4	786.0
9.7	6.6	23.2	66.6	46.5	721.0
9.8	7.2	24.6	90.4	46.5	823.0
9.8	7.7	26.8	117.8	46.8	712.0
9.9	5.8	27.3	142.7	47.1	754.0
10.2	5.6	28.6	120.9	47.2	625.0
10.2	7.0	31.2	180.7	47.8	796.0
10.4	7.6	33.1	215.0	48.1	814.0
10.4	8.1	35.1	265.0	48.8	856.0
10.7	9.3	35.6	278.0	48.9	865.0
10.8	7.0	35.8	284.0	49.1	875.0
10.8	8.1	36.0	290.0	49.8	920.0
10.9	7.6	36.0	290.0	50.2	950.0
10.9	7.6	36.2	295.0		
11.4	10.2	36.3	298.0		
11.5	9.4	36.5	305.0		
11.7	11.5	36.9	316.0		
11.7	11.5	37.2	324.0		
12.1	11.1	37.2	325.0		
12.2	12.3	37.2	471.0		
12.2	12.3	37.7	340.0		
12.3	11.0	38.4	365.0		
12.4	13.6	39.0	385.0		
12.5	11.2	39.3	395.0		
12.8	9.7	39.6	405.0		
13.3	11.7	39.9	416.0		
13.3	13.3	40.6	480.0		
13.5	13.0	40.9	458.0		
13.5	14.9	41.0	462.0		
13.6	16.7	41.3	574.0		
13.8	17.5	42.1	504.0		
14.2	10.1	42.2	510.0		
14.5	18.3	42.4	520.0		
15.1	17.9	42.6	527.0		
15.1	22.2	42.9	542.0		

Appendix Table 2 The data used for length-weight relationship by weighted least square.

Mid Total Length (cm)	**Average Weight (g)**	**Weight Frequency**
3.5	0.70	1
6.5	2.40	1
8.5	3.93	4
9.5	5.89	10
10.5	10.59	9
11.5	10.65	4
12.5	11.60	7
13.5	14.52	6
14.5	14.20	2
15.5	20.05	2
16.5	28.30	1
17.5	25.10	1
18.5	31.60	3
19.5	42.63	3
20.5	55.00	2
21.5	50.45	2
23.5	66.60	1
24.5	90.40	1
26.5	117.80	1
27.5	142.70	1
28.5	120.90	1
31.5	180.70	1
33.5	215.00	1
35.5	275.67	3
36.5	299.00	6
37.5	365.00	4
38.5	365.00	1
39.5	400.25	4
40.5	469.00	2
41.5	518.00	2
42.5	520.60	5
43.5	606.25	4
44.5	611.67	3
45.5	640.33	3
46.5	772.20	5
47.5	725.00	3
48.5	845.00	3
49.5	897.50	2
50.5	950.00	1
		116

Appendix Table 3 Length frequency distribution data.

Length (cm)	**2003**												**2004**						
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
6			1																
7																			
8			4																
9			11	1		1													
10			10	3	3	2											1		
11		3	8	2	9	1									1	1	2	2	
12	5	4	12	1	9	1										1		1	
13	9	1	12	1	7	1	1											1	
14	10	6	14	2	3					1	4		1	1	1	3			
15	14	7	18	3	7	1				10	18		6	6	1	2	1		
16	10	8	8	4	3	3				3	2		5	1	1	1	1		
17	6	16	15	5	1	2				4	18	2	7	4	2	1	1		
18	11	14	15	7	4	3				4	13	12	11	8	3	2	6		
19	9	14	22	13	11	1				7	14	19	23	6	3	4	5		
20	15	13	14	14	13	5				29	59	33	12	8	11				
21	12	31	15	11	9	4				12	17	24	14	11	5	1	2		
22	18	24	20	5	15	3	1			15	20	23	18	6	4	2	3		
23	27	21	19	18	8	2		2		13	30	37	12	9	5	9	9	1	
24	24	28	19	16	5	1	1	1	1	30	37	44	18	15	9	14	4	2	1
25	18	15	17	5	7	4	3	1	2	34	46	35	27	20	13	10	8	1	1
26	16	12	8	7	7	2	1	2	1	11	28	38	26	14	5	3	6	3	2
27	16	23	18	3	1		1	1	4	15	39	25	18	28	11	4	10		1
28	23	19	15	7	1	1			4	15	3	30	11	18	15	4	7		
29	11	14	7	15	7	1			1	4	5	17	4	27	2		2		

Appendix Table 3 (cont'd) Length frequency distribution data.

Length (cm)	**2003**									**2004**									
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
30	16	18	12	8	5	6		1		36	15	12	12	19	13	15	7	1	1
31	25	12	16	6	2	2	1	2	1	9	28	11	20	11	6	3	5	2	1
32	14	11	9	7	4	1	2	1	1	19	3	5	14	9	5	7	2	2	1
33	15	15	4	10	6		1	3	2	17	15	4	2	9	2		2	3	
34	12	6	8	4	1		1	1	2	6	2	19	2	7	1	2	2		
35	8	9	6	7	1	2			1	9	7	16	8	6	10	8	3		
36	3	3	7	3						3	2	3	3	13	2	2	4		
37	7	1	1	5		1				6		6	3	13	2		1		
38	2	2	4	1		3				2	4	6	2	6	1				
39	4	6	4	3	1	1				1	1	1	3	3	3	1			
40	6	4	7	5	1	4				3	2	1	4	3	3	1	3		
41	3	1	1	2	1	1				7	2	7	2	3	3	3			
42	4	2	2	4		2				1	1	1	3	3	2				
43	1			1						2	2	5	1	2	2				
44		1	1		1					1	4	5	3	7	1	1			
45	2		2	1							1	1	2	4	3		2		
46			2	2						1		3	3	3			1		
47			1	1						3		1	4	5	1				
48	1			1						1		1	2	2	1				
49										1	1	1	1						
50												1	1						
51																			
52											1		1						
53																			
54													1						
sum	**377**	**364**	**389**	**214**	**153**	**62**	**13**	**15**	**20**	**335**	**444**	**449**	**310**	**310**	**153**	**105**	**100**	**19**	**8**

Appendix Table 4 Gonadosomatic Index (GSI) data followed by sampling station.

Station 1			**Station 2**			**Station 3**			**Station 4**			**Station 5**		
Month	GSI	s.d.	Month	GSI	s.d.	Month	GSI	s.d.	Month	GSI	s.d.	Month	GSI	s.d.
Jul-03	1.826	2.84	Jul-03	0.45	0.71	Jul-03	5.96	1.63	Jul-03	3.40	2.40	Jul-03	3.56	2.67
Aug-03	0.5375	0.34	Aug-03	0.66	0.53	Aug-03	0.10	0.04	Aug-03	0.11	0.04	Aug-03	3.56	2.67
Sep-03	0.73	0.21	Sep-03	0.53	0.42	Sep-03	0.15	0.04	Sep-03	0.33	0.08	Sep-03	0.13	0.08
Oct-03	0.04533	0.03	Oct-03	0.09	0.05	Oct-03	0.08	0.02	Oct-03	0.03	0.03	Oct-03	0.02	n.a.
Nov-03	0.59	0.94	Nov-03	1.03	1.39	Nov-03	0	n.d.	Nov-03	0.20	n.a.	Nov-03	0	n.d.
Dec-03	0.59	n.a.	Dec-03	0	n.d.	Dec-03	0.2	n.a.	Dec-03	0	n.d.	Dec-03	0	n.d.
Jan-04	1.37	1.00777	Jan-04	1.17	1.55563	Jan-04	0	n.d.	Jan-04	0	n.d.	Jan-04	0.03	n.a.
Feb-04	3.0125	0.64603	Feb-04	2.92333	1.01106	Feb-04	0	n.d.	Feb-04	0	n.d.	Feb-04	0	n.d.
Mar-04	3.63429	1.5	Mar-04	2.5	1.1	Mar-04	0	n.d.	Mar-04	0	n.d.	Mar-04	0	n.d.
Apr-04	3.31167	1.21	Apr-04	3.54	1.41	Apr-04	0	n.d.	Apr-04	0	n.d.	Apr-04	0	n.d.
May-04	4.23333	2.45	May-04	4.41	1.89	May-04	0	n.d.	May-04	6.83	n.a.	May-04	3.07	n.a.
Jun-04	4.175	1.73	Jun-04	4.18	2.50	Jun-04	4.85	0.89	Jun-04	4.10	2.54	Jun-04	4.78	1.84
Jul-04	1.95	2.73	Jul-04	2.99	2.30	Jul-04	5.18	1.27	Jul-04	3.26	2.71	Jul-04	1.40	2.31
Aug-04	0.092	0.03	Aug-04	0.26	0.42	Aug-04	0.12	0.05	Aug-04	0.28	0.14	Aug-04	0.35	0.55
Sep-04	0.11667	0.04509	Sep-04	0.06667	0.03512	Sep-04	0.04333	0.03512	Sep-04	0.07	0.04082	Sep-04	0.142	0.08643
Oct-04	0.08333	0.04041	Oct-04	0.1	0.05657	Oct-04	0.2975	0.38274	Oct-04	0.1	0.05657	Oct-04	0.04	n.a.
Nov-04	0.02	0.01	Nov-04	0.02	n.a.	Nov-04	0	n.d.	Nov-04	0	n.d.	Nov-04	0.04	n.a.
Dec-04	0.025	0.00707	Dec-04	0	n.d.	Dec-04	0	n.d.	Dec-04	0	n.d.	Dec-04	0	n.d.

n.a. = non analyse; n.d. = no data

Appendix Table 5 Egg profile data separated by month.

Month	Mean Total Length (cm)	Fecundity
Mar.	40.5	101,000
	43.5	101,000
	47.5	87,542
	48.5	75,000
Apr.	40.5	110,246
	42.5	44,952
	44.5	72,358
	51.5	50,247
May	37.5	126,357
	42.5	35,687
	43.5	45,712
	46.5	74,356
	46.5	74,356
	47.5	88,352
	49.5	113,245
	50.5	94,367
June	35.5	187,000
	37.5	35,442
	39.5	85,250
	39.5	35,620
	39.5	45,358
	39.5	48,955
	41.5	54,720
	42.5	54,215
	42.5	40,722
	45.5	65,254
	48.5	66,500
	48.5	95,471
	49.5	185,470
	52.5	92,540
	54.5	105,640
July	33.5	55,235
	35.5	46,550
	36.5	21,547
	36.5	39,050
	36.5	44,385
	36.5	60,255
	36.5	75,437
	36.5	81,000
	41.5	135,420
	42.5	74,260
	43.5	57,366
	44.5	87,266
	44.5	102,650
	45.5	129,000
	45.5	164,000
	46.5	100,250
	46.5	171,000
	46.5	191,539

Appendix Table 6 Fecundity data.

No.	Length	Fecundity
1	33.1	55,235
2	35.1	35,442
3	35.6	46,550
4	35.8	22,454
5	36.0	21,547
6	36.0	81,000
7	36.2	44,385
8	36.3	75,437
9	36.5	39,050
10	36.9	60,255
11	37.2	85,250
12	37.2	35,687
13	37.2	88,060
14	37.7	66,510
15	38.4	65,300
16	39.0	48,955
17	39.3	54,720
18	39.6	45,358
19	39.9	35,620
20	40.6	101,000
21	40.9	44,952
22	41.0	54,215
23	42.1	40,722
24	42.2	65,254
25	42.4	72,358
26	42.6	74,260
27	42.9	45,712
28	43.5	74,356
29	43.7	57,366
30	43.8	87,542
31	44.2	87,266
32	44.4	102,650
33	44.7	50,247
34	45.3	66,500
35	45.7	129,000
36	46.0	74,356
37	46.4	88,352
38	46.5	100,250
39	47.1	102,455
40	47.2	75,000
41	47.8	113,245
42	48.8	95,471
43	48.9	110,246
44	49.1	94,367
45	49.8	92,540
46	51.7	126,357
47	52.5	105,640
48	54.2	145,400

Appendix Table 7 Sex steroid hormones and water qualities data.

	Sex Hormones (ng)			Water Qualities		
Month	**Testosterone**	**Estradiol**	**Progesterone**	**Rainfall (NTU)**	**Turbidity (NTU)**	**Temperature (^oC)**
Jul-03				196	63	31.1
Aug-03				204	46.66	31.72
Sep-03				125	9	31.1
Oct-03				85	8.4	30.2
Nov-03				42	6.5	27.7
Dec-03				23	8.7	26.2
Jan-04	0.1450	0.1408	0.0100	7	6.7	24.1
Feb-04	0.1133	0.0540	0.0200	16	8.4	26.1
Mar-04	0.2967	0.3480	0.1700	29	12.61	30.5
Apr-04	0.9600	0.2587	0.5167	86	14.73	32.16
May-04	0.7175	1.1353	0.5767	209	40.3	30.8
Jun-04	0.4167	12.6200	0.1983	287	57.334	29.7
Jul-04	0.1317	9.6885	0.0767	266	58.698	30.31
Aug-04	0.0600	1.7618	0.0217	235	44.1	29.71
Sep-04	0.0267	1.0035	0.0117	104	28.052	29.67
Oct-04	0.0150	0.2378	0.0117	45	26.644	26.3
Nov-04	0.0250	0.2605	0.0083	10	7.6	24.9
Dec-04	0.0250	0.9825	0.0100	5	3.4	24.7

Appendix Table 8 The egg stage followed by month in each station.

Station	**Month**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
1	Jul-03	2	0	0	0	1	2	5
2	Jul-03	3	0	0	0	0	1	4
3	Jul-03	0	0	0	1	1	0	2
4	Jul-03	0	0	0	1	1	2	4
5	Jul-03	1	0	0	2	1	1	5
Station	**SUM**	**6**	**0**	**0**	**4**	**4**	**6**	**20**
1	Aug-03	4	0	0	0	0	0	4
2	Aug-03	3	0	0	0	0	0	3
3	Aug-03	4	0	0	0	0	0	4
4	Aug-03	6	0	0	0	0	0	6
5	Aug-03	4	0	0	0	0	0	4
Station	**SUM**	**21**	**0**	**0**	**0**	**0**	**0**	**21**
1	Sep-03	4	0	0	0	0	0	4
2	Sep-03	3	0	0	0	0	0	3
3	Sep-03	3	0	0	0	0	0	3
4	Sep-03	2	0	0	0	0	0	2
5	Sep-03	2	0	0	0	0	0	2
Station	**SUM**	**14**	**0**	**0**	**0**	**0**	**0**	**14**
1	Oct-03	3	0	0	0	0	0	3
2	Oct-03	2	0	0	0	0	0	2
3	Oct-03	2	0	0	0	0	0	2
4	Oct-03	2	0	0	0	0	0	2
5	Oct-03	1	0	0	0	0	0	1
Station	**SUM**	**10**	**0**	**0**	**0**	**0**	**0**	**10**
1	Nov-03	2	1	0	0	0	0	3
2	Nov-03	1	1	0	0	0	0	2
3	Nov-03	0	0	0	0	0	0	0
4	Nov-03	1	0	0	0	0	0	1
5	Nov-03	0	0	0	0	0	0	0
Station	**SUM**	**4**	**2**	**0**	**0**	**0**	**0**	**6**
1	Dec-03	0	1	0	0	0	0	1
2	Dec-03	0	0	0	0	0	0	0
3	Dec-03	1	0	0	0	0	0	1
4	Dec-03	0	0	0	0	0	0	0
5	Dec-03	0	0	0	0	0	0	0
Station	**SUM**	**1**	**1**	**0**	**0**	**0**	**0**	**2**
1	Jan-04	1	2	0	0	0	0	3
2	Jan-04	1	1	0	0	0	0	2
3	Jan-04	0	0	0	0	0	0	0
4	Jan-04	0	0	0	0	0	0	0
5	Jan-04	1	0	0	0	0	0	1
Station	**SUM**	**3**	**3**	**0**	**0**	**0**	**0**	**6**

Appendix Table 8 (cont'd) The egg stage followed by month in each station.

Station	**Month**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
1	Feb-04	0	2	2	0	0	0	4
2	Feb-04	0	2	1	0	0	0	3
3	Feb-04	0	0	0	0	0	0	0
4	Feb-04	0	0	0	0	0	0	0
5	Feb-04	0	0	0	0	0	0	0
Station	**SUM**	**0**	**4**	**3**	**0**	**0**	**0**	**7**
1	Mar-04	0	2	2	3	0	0	7
2	Mar-04	0	3	1	1	0	0	5
3	Mar-04	0	0	0	0	0	0	0
4	Mar-04	0	0	0	0	0	0	0
5	Mar-04	0	0	0	0	0	0	0
Station	**SUM**	**0**	**5**	**3**	**4**	**0**	**0**	**12**
1	Apr-04	0	2	2	2	0	0	6
2	Apr-04	0	1	2	2	0	0	5
3	Apr-04	0	0	0	0	0	0	0
4	Apr-04	0	0	0	0	0	0	0
5	Apr-04	0	0	0	0	0	0	0
Station	**SUM**	**0**	**3**	**4**	**4**	**0**	**0**	**11**
1	May-04	0	0	0	2	2	2	6
2	May-04	0	0	1	1	2	1	5
3	May-04	0	0	0	0	0	0	0
4	May-04	0	0	0	0	1	0	1
5	May-04	0	0	1	0	0	0	1
Station	**SUM**	**0**	**0**	**2**	**3**	**5**	**3**	**13**
1	Jun-04	0	0	0	2	1	1	4
2	Jun-04	0	0	0	2	1	1	4
3	Jun-04	0	0	1	3	1	0	5
4	Jun-04	0	0	0	1	3	2	6
5	Jun-04	0	0	1	2	3	1	7
Station	**SUM**	**0**	**0**	**2**	**10**	**9**	**5**	**26**
1	Jul-04	3	0	0	1	1	1	6
2	Jul-04	0	0	0	1	1	2	4
3	Jul-04	0	0	0	3	1	0	4
4	Jul-04	1	0	0	1	2	2	6
5	Jul-04	3	0	0	0	1	2	6
Station	**SUM**	**7**	**0**	**0**	**6**	**6**	**7**	**26**
1	Aug-04	5	0	0	0	0	0	5
2	Aug-04	3	0	0	0	0	1	4
3	Aug-04	2	0	0	0	0	0	2
4	Aug-04	2	0	0	0	0	0	2
5	Aug-04	3	0	0	0	0	1	4
Station	**SUM**	**15**	**0**	**0**	**0**	**0**	**2**	**17**

Appendix Table 8 (cont'd) The egg stage followed by month in each station.

Station	**Month**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
1	Sep-04	3	0	0	0	0	0	3
2	Sep-04	3	0	0	0	0	0	3
3	Sep-04	3	0	0	0	0	0	3
4	Sep-04	4	0	0	0	0	0	4
5	Sep-04	5	0	0	0	0	0	5
Station	**SUM**	**18**	**0**	**0**	**0**	**0**	**0**	**18**
1	Oct-04	3	0	0	0	0	0	3
2	Oct-04	2	0	0	0	0	0	2
3	Oct-04	4	0	0	0	0	0	4
4	Oct-04	2	0	0	0	0	0	2
5	Oct-04	1	0	0	0	0	0	1
Station	**SUM**	**12**	**0**	**0**	**0**	**0**	**0**	**12**
1	Nov-04	3	0	0	0	0	0	3
2	Nov-04	1	0	0	0	0	0	1
3	Nov-04	0	0	0	0	0	0	0
4	Nov-04	0	0	0	0	0	0	0
5	Nov-04	1	0	0	0	0	0	1
Station	**SUM**	**5**	**0**	**0**	**0**	**0**	**0**	**5**
1	Dec-04	2	0	0	0	0	0	2
2	Dec-04	0	0	0	0	0	0	0
3	Dec-04	0	0	0	0	0	0	0
4	Dec-04	0	0	0	0	0	0	0
5	Dec-04	0	0	0	0	0	0	0
	SUM	**2**	**0**	**0**	**0**	**0**	**0**	**2**
Grand total		**118**	**18**	**14**	**31**	**24**	**23**	**228**

Appendix Table 9 The data used for gillnet selectivity.

Mean TL	**Mesh size (cm)**		
	4.5	**5.5**	**6.5**
14	9	1	0
15	39	2	2
16	9	3	0
17	26	10	2
18	33	10	6
19	44	15	8
20	101	32	5
21	49	23	6
22	57	18	8
23	64	32	4
24	89	48	10
25	162	105	10
26	51	51	9
27	53	38	17
28	31	37	16
29	12	13	10
30	21	39	28
31	7	22	15
32	9	23	16
33	0	12	9
34	0	7	15
35	3	20	19
36	2	4	12
37	0	2	7
38	0	0	15
39	0	1	4
40	0	1	13
41	0	2	11
42	0	2	5
43	0	0	3
44	0	1	7
45	0	0	6
46	0	0	3
47	0	0	5
48	0	0	4
49	0	0	1
Total	871	574	311

Appendix Table 10 The data used for hook selectivity.

Mean TL	**Mar.**	**Apr.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Total**
14						1		1
15							1	1
16						1	1	2
17							1	1
18					1	1	1	3
19	1			1		1	1	4
20				2	3			5
21	3		2					5
22	1	1		2		2	1	7
23						1		1
24	3				1		1	5
25		2	3		1	2		8
26		1		3				4
27	1	3	3	1	1		1	10
28	1		1	2	1			5
29				1				1
30	1		1		1	3	1	7
31	1	2	1	1	2			7
32	1					1		2
33			2	2		1	1	6
34		2	2				1	5
35	1	1	1	1	2		1	7
36		2	1					3
37				2				2
38								0
39			1	2				3
40			2	1				3
41					1			1
42				1				1
43					1			1
44								0
45				2	1			3
46								0
47			1					1
48				1				1
Total	14	14	21	25	16	14	12	116

CURRICULUM VITAE

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