TEMPORAL AND SPATIAL DISTRIBUTION OF FISH LARVAE AND THEIR ENVIRONMENTAL BIOLOGY IN PHANG-NGA BAY, THAILAND

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ABSTRACT

A one year study of the seasonal and spatial distribution of fish larvae and environmental parameters (physico-chemical variables, phytoplankton biomass and production) was carried out in Phang-Nga Bay, eastern Andaman Sea, Thailand. In all, 14 stations were sampled on 10 occasions. Altogether 48 larval fish families were identified and more than 60% of the larvae belonged to commercially important families. There was a pronounced seasonal pattern in larval fish abundance with average concentration during January-March being approximately twice the average concentration during the rest of the year. This seasonal pattern was unrelated to the (weak) seasonal variation in phytoplankton biomass and production, which, in turn, was unrelated to the seasonally very variable availability of inorganic nutrients and precipitation. Spatial trends showed larval fish abundance and family diversity to increase from the innermost to the outermost part of the bay. The concentrations of chlorophyll-a and nitrate and turbidity showed the opposite trend. The abundance of fish larvae was negatively related to turbidity. Mechanisms of regulating plankton productivity and adaptations of fish spawning periods to events in the plankton in Phang-Nga Bay are discussed.

INTRODUCTION

The abundance, growth and survival of fish larvae determine the recruitment to the fish stocks and, hence, significantly influence the magnitude of fisheries in the sea. Yet, basic information on seasonal and spatial distribution and on taxonomic composition of ichthyoplankton in tropical waters is relatively scarce. In Thai waters a few investigations have been carried out in the Gulf of Thailand (e.g. Boonprakob, 1962, 1965; Boonprakob and Dheptaranon, 1971; Chayakul and Uttapong, 1983a, 1983b; Pornpatimakorn and Chayakul, 1986; Vatanachai, 1979a, 1979b), but very little is known about fish larvae on the Andaman coast of Thailand.

Within the last decade ichthyoplankton studies have been carried out at the Phuket Marine Biological Center (PMBC) in the eastern Andaman Sea. In a previous paper the seasonal occurrence of fish larvae in the mangrove channels of Phang-Nga Bay was described (Janekarn and Boonruang, 1986), and in this paper the occurrence of fish larvae in Phang-Nga Bay is considered. Janekarn and Kjørboe (1991) describe the distribution of fish larvae in the open eastern Andaman Sea. All of these studies identify the fish larvae only to the family level but they provide baseline information for more detailed studies on selected taxa in the future.

Attempts to characterize the fish larval fauna of the Andaman coast of Thailand have been paralleled by efforts to describe the pelagic environment encountered by the fish larvae. Thus, studies on phytoplankton production (Wium-Andersen, 1977, 1979; Sundström et al., 1987; Janekarn and Hylleberg, 1989), zooplankton distribution (Boonruang, 1985), and the physico-chemical environment (Yesaki and Jantarapagdee, 1981; Sundström et al., 1987; Janekarn and Hylleberg, 1989) have been carried out at the PMBC. In the present study we attempt to combine information on the spatio-temporal occurrence of fish larvae in Phang-Nga Bay with measurements of environ-
mental factors (i.e. physico-chemical parameters, phytoplankton biomass and production). In particular we investigate to what extent seasonal variation in fish larval abundance is related to seasonal variation in plankton production. It is commonly assumed that primary production (and, hence, zooplankton production) in tropical nearshore waters is elevated during the wet monsoon season due to nutrient enrichment of the euphotic zone caused by land run-off (Longhurst and Pauly, 1987; Qasim, 1974; Robertson et al., 1988). Available data from Phang-Nga Bay tend to support this pattern (Sundström et al., 1987), although the evidence is somewhat contradictory (Wium-Andersen, 1979; Boonruang, 1985). It has been suggested that resident fish have spawning periods adapted to such seasonal variation in the availability of food for their larvae (Ursin, 1984), as has been clearly documented in temperate waters (e.g. Cushing, 1975). Determination of spawning periods for commercially important fish, as well as understanding of the underlying causalties behind seasonal patterns, have obvious implications for fisheries management. We also investigate to what extent patterns in the distribution of fish larvae in the bay are related to environmental factors, and finally we attempt to evaluate the importance of Phang-Nga Bay as a nursery area for larval fish.

MATERIALS AND METHODS

Study area

Phang-Nga Bay (Fig. 1) is a coastal bay in Southern Thailand connected to the Andaman Sea and located in a wet tropical climate. The bay area is approximately 2,000 km² and it is highly productive with an annual primary productivity of approximately 400 gC m⁻² (Sundström et al., 1987). Mangroves line the shores of the bay and are especially dense in the interior portions where canals are located. Water depth in the western and inner parts of the bay is less than 10 m while the eastern and outer parts are deeper, up to 24 m (Table 1). Tidal amplitude is 1-2 m, and the speed of the tidal currents is up to 3-5 km hr⁻¹ (Wium-Andersen, 1979; Limpaichol, 1981). The bay is dotted with islands of which Yao Yai and Yao Noi Islands in the middle of the bay are by far the largest. The study area is influenced by distinct wet (April-October) and dry (November-March) seasons. During the wet season strong winds blow from the south-southwest and large waves sweep the area. The inner portion of the bay is partly protected by the two large islands. Heavy precipitation occurs and freshwater from tributaries enters the bay. In contrast, during the dry season large waves appear more in the inner part than elsewhere but are of lesser strength than those in the wet season.

Fig. 1. Map of Phang-Nga Bay with positions of sampling stations indicated.
Table 1. Mean depths of sampling stations.

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Period of sampling

Fourteen stations were sampled monthly (Fig. 1), from January through December 1984, except April [when only 2 stations (i.e. D and 10) were visited due to weather conditions] and June (Table 1). Each cruise was of 7-8 days duration so that all sampling sites could be visited. Samples were taken just once at each site during a cruise. During the wet monsoon, calm days were selected for the cruises. All samples and measurements were taken during daytime.

Fish larvae

A modified WP-3 conical net (ICES/SCOR/UNESCO Working Group; UNESCO, 1968) with an opening diameter of 75 cm, a length of 230 cm and a mesh size of 0.505 mm, was used. The net was equipped with a TSK flowmeter model 1201. Oblique towings were made at a speed of 1-2 knots to maintain a wire angle of about 45°. Each tow took approximately 10 minutes (excluding wire payout time) and was equally stepped between three depth intervals, i.e. close to the sea bed, in the middle of the water column and near the surface. The sampler was rapidly lowered (about 30-40 m/min) to as near the bottom as possible while the ship was slowly underway (<1 knot). Volume filtered per tow varied between 169 and 394 m³. After each tow the net was rinsed thoroughly into the cod-end with sea water. Formaldehyde neutralized with sodium borate was immediately added to the zooplankton samples to bring a final concentration of 10% formalin. Later, fish larvae were sorted out and transferred to 4% neutralized formaldehyde.

Fish larvae were identified to family level, except for an eel leptcephalus and members of the Serranidae, and subsequently counted. Serranid larvae were identified to subfamily, i.e. Serraninae, Anthiinae and Epinephelinae, following the paper of Kendall (1979). Counts of larvae per haul were converted to numbers per 1,000 m³ of water filtered.

Identification was based on the occurrence of adult features in larval forms. Four major criteria as proposed by E. H. Ahlstrom (UNESCO, 1975) were utilized. These were morphometrics, meristics, pigmentation and specialized larval characters (such as conspicuously serrated supraoccipital crest united with a large spine in Leiognathidae). Sources of information for larval identification included papers by Fahay (1983), Leis and Rennis (1983), Moser et al. (1984), and the six volumes of "Development of fishes of the mid-Atlantic Bight" (Jones et al., 1978; Hardy, 1978a, 1978b; Johnson, 1978; Fritzsche, 1978; Martin and Drewry, 1978). The papers by Vatanachai(1972, 1979a, 1979b) and Janekarn and Boonruang (1986) were particularly useful for primary identification owing to the similarity of the fish larvae fauna in those studies and in the present one.

Environmental conditions

Sea water was collected concurrently with fish larvae by a modified fibreglass and stainless steel 3 litres Ruttner sampler. At stations 1 to 10 water collections were made at 1 m below the surface and 1 m above the sea bed. At the stations A-D, samples were also collected at 3-4 additional depths equally distributed through the water column. Temperature was measured
by a thermometer (0.1°C), salinity determined by AgNO₃ titration, and inorganic nutrients (NO₃, PO₄) and chlorophyll-a (Chl) were analysed following Strickland and Parsons (1972). For Chl determination, one litre samples were filtered through Whatman GF/C filter paper. The filters were homogenized in a tissue grinder and pigments extracted overnight in 10 ml 90 % acetone. Chl was determined spectrophotometrically and concentrations were calculated by the equations of Jeffrey and Humphrey (1975). Secchi depths were recorded at the time water samples were taken.

Primary productivity

Primary productivity was measured at stations A-D by the C¹⁴ method as described by Sundström et al. (1987). All productivity measurements were carried out in situ, usually over a four hour period around noon. Approximately 4 μCi of C¹⁴ as NaHCO₃ were added to each Jena bottle (about 110 ml) and then incubated at the 5-6 sampling depths. After incubation, the samples were filtered onto Sartorius membrane filters (0.2 μm pore size). Thereafter, radioactivity was determined by a Geiger-Müller counter. Light intensity (relative units) was measured on deck by a set of 4 photocells connected to an ohm-meter and recorded every 0.5 h through the day. Primary productivity rates were determined at each depth according to the methods of Vollenweider (1971). Daily production throughout the water column was calculated by integrating data from the different depths and taking the measured light cycle into account (Dyson et al., 1965).

RESULTS

Temporal and spatial changes in larval fish assemblages in relation to water properties are the themes of this paper. The results will be presented in five paragraphs, viz. environmental variables, spatial and seasonal trends in fish larval diversity, larval abundance, distribution of predominant families, and relations between fish larval abundance and environmental variables.

ENVIRONMENTAL VARIABLES

Precipitation

The total annual rainfall in 1984, measured at 9 meteorological stations bordering Phang-Nga Bay and considered representative of the bay drainage area, varied between 1675 and 1800 mm (Data obtained from the Meteorological Department, Bangkok). Almost all rain fell between April and October but during the wet season there was considerable temporal variation between stations (Fig. 2).

![Graph showing monthly precipitation in 1984 at selected meteorological stations around Phang-Nga Bay.](image-url)
Secchi depths

Secchi depths (Fig. 3) varied between 1 and 11 m. It was lowest at the innermost shallow stations (i.e., 3, 4, 5 and 7) located close to mangrove areas and channels and increased towards the mouth of the bay to peak at the outermost stations (i.e., 9 and 10, Fig. 9a). Seasonal variation in water transparency generally showed a bimodal pattern with peaks in August-September and March more or less evident at most stations.

Temperature

Seawater temperature (Fig. 4) varied between 26.5 and 30.5°C. As with secchi depth, temperature showed a bimodal pattern with peaks in March-April and again in September. Horizontal gradients in surface temperatures were small. Averaged over the entire year seaward stations had slightly lower temperature (by 0.5°C) than innermost stations. Vertical temperature stratification was very weak with difference in surface and bottom temperature generally <1°C.

Salinity

Average salinity (Fig. 5) peaked in March-April at the end of the dry season (32.26 and 32.05 ° at the surface, and 32.34 and 32.25 at the bottom, respectively) and decreased during the wet season to reach a minimum in September (30.2 and 30.5 ° at the surface and

Fig. 3. Annual variation in secchi depth (m) at stations A-D during 1984 in Phang-Nga Bay. These stations are considered representative for the bay.

Fig. 4. Annual variation in surface (●●●) and bottom (●●●●) temperature (°C) at station A-D during 1984 in Phang-Nga Bay.

Fig. 5. Annual variation in surface (●●●) and bottom (●●●●) salinity (%) at stations A-D during 1984 in Phang-Nga Bay.
Nutrients

Inorganic nutrients (Figs. 6, 7 and 8), NO$_3$ and PO$_4$, followed similar seasonal trends with low concentrations (<0.5 µg-at l$^{-1}$) in the first half of the year and significantly higher concentrations from September onwards (Figs. 6 and 7). Between January and March the concentration of NO$_3$ was particularly low, often below detection level, and may at times have been limiting to primary productivity. There was no apparent seasonal relation between precipitation (Fig. 2) and concentration of inorganic nutrients. Bay-wide monthly average surface concentrations of NO$_3$ and PO$_4$ showed a significant correlation (Fig. 8, $r^2 = 0.80$, N=10, P < 0.05).

In contrast to the seasonal patterns spatial patterns in NO$_3$ and PO$_4$ concentrations were quite different. Surface and bottom concentrations of PO$_4$ were similar, while bottom concentrations of NO$_3$ were almost always higher than surface concentrations. Also, a significant spatial pattern was evident in the distribution of NO$_3$, with maximum concentrations in the innermost parts of the bay (Fig. 9b). There was no consistent spatial pattern in PO$_4$ distribution. Consequently, the average concentrations of NO$_3$ and PO$_4$ by
Fig. 9. Spatial distribution of a) Secchi Depth (m, annual average), b) bottom NO$_3$ concentration (μg-at l$^{-1}$, annual average), c) surface salinity (% o S, July-October) and d) bottom concentration of chlorophyll-a (μg Chl l$^{-1}$, annual average).
station were not significantly intercorrelated \( (r^2 = 0.08, N=14) \). The high NO₂ concentrations in the inner parts of the bay suggest that mangrove channels are a significant source of inorganic nutrients.

The observed ratio between dissolved inorganic P and N was always very much in excess of the Redfield-ratio of 1:16 (by atoms) (see Fig. 8), thus suggesting that if and whenever inorganic nutrients were limiting primary production, nitrogen would be the limiting constituent (cf. above). The very high P:N ratio explains why PO₄ is almost homogenously distributed in the bay while NO₃ showed distinct horizontal and vertical patterns; only an insignificant fraction of the phosphate is utilized by the phytoplankton.

Chlorophyll-a (Chl a)

Chl a (Fig. 10) is an indicator of phytoplankton biomass. The distribution of Chl a showed a clear spatial pattern with highest concentrations at innermost stations and declining concentration in seaward direction (Fig. 9d). In contrast, the seasonal variation did not show a clear pattern and there was little consistency between stations. However, peaks in May occurred at many stations and the average concentrations (all stations) showed a seasonal maximum (surface: 2.66 mg m⁻³; bottom: 3.41 mg m⁻³) in May. There was a consistent vertical distributional pattern of Chl a, with bottom concentrations almost invariably being considerably higher than surface concentrations.

Pelagic primary productivity (PP)

PP (Fig. 11) averaged over the whole year was well above 1 gC m⁻² d⁻¹ at station A, B and C but only 0.74 gC m⁻² d⁻¹ at station D. On one occasion (December), extremely high PP (5.51 gC m⁻² d⁻¹) was measured at station C. Spatial and seasonal variation largely followed variation in concentrations of Chl a, and primary production and Chl a were significantly intercorrelated \( (r^2 = 0.77, N=41, P<0.01) \). As for Chl a, the seasonal pattern was not very pronounced nor consistent between stations, except for low production in August-September and relatively low production in January-March at all stations.

![Fig. 10. Annual variation in surface (—) and bottom (—) chlorophyll-a (µg Chl l⁻¹) at stations A-D during 1984 in Phang-Nga Bay.](image)

![Fig. 11. Annual variation in primary production (mgC m⁻² d⁻¹) and chlorophyll (mg Chl m⁻³) at stations A-D during 1984 in Phang-Nga Bay.](image)
SPATIAL AND SEASONAL TRENDS IN FISH LARVAL DIVERSITY

A total of 4,199 larval fish including 48 families and an eel leptcephalus were collected (see Table 2). The family Serranidae was present as three subfamilies, i.e. Serraninae, Anthiinae and Epinephelinae. All larvae of family Scombridae were identified as Rastrelliger spp. The families Bregmaceroitdae, Leiognathidae, Sciaenidae and Cynoglossidae were most common in the collection. Larvae of these families were found on every cruise while larvae of the families Engraulidae, Carangidae, Gobiidae and Callionymidae were found on all but one cruise (see Table 2). Other families, e.g. Clupeidae, Syngnathidae, Apogonidae, Blenniidae, Scorpaenidae, Platyccephalidae, Trigidae, Bothidae, Soleidae and Monacanthidae, were also found frequently. However, many families were truly rare, only occurring in samples from one to three cruises (Table 2).

The number of families identified at each station or in each month was quite variable (From 16 to 32 and 10 to 31 families, respectively). However, the number of families was mainly a function of the sample size; i.e. the larger the number of larvae collected the greater the number of families identified (Fig. 12 a & b). Eighty percent of the seasonal and 75 % of the spatial variation in family diversity was due to variation in sample size ($r^2$ equal to 0.80 and 0.75, respectively). On the seasonal scale only two months deviated significantly; viz. August and October with higher (i.e. above regression line) and lower than averaged family diversity, respectively (Fig. 12a). On the spatial scale less of the variation in diversity was related to sample size. Outermost stations tended to have higher and innermost stations lower than average diversity (Fig. 12b).

Larvae of Engraulidae, Leiognathidae, Sciaenidae, Gobiidae, Trigidae, Callionymidae, Cynoglossidae and Monacanthidae were evenly distributed in the bay whilst those of Bregmaceroitdae, Mugilidae, Apogonidae, Sillaginidae, Carangidae, Nemipteridae,

Fig. 12. Total number of families identified in each month (a) or at each station (b) as a function of the number of larvae collected. Regression lines and 95 % confidence limits have been indicated. Numbers in (b) refer to stations.
Table 2. Total numbers of fish larvae of each family caught in each cruise during 1984.

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TOTAL 753 512 602 77 354 559 347 145 455 208 187 4199
Blenniidae, Scorpaenidae, Platycephalidae, Bothidae and Soleidae were also widely, but not uniformly, present in the study area. Other families were sporadically distributed (Table 2).

**LARVAL ABUNDANCE**

Table 3 shows the concentrations of larvae by month and station. The concentration of larvae differed significantly between hauls (0 to 1,025 larvae 1,000 m⁻³). The greatest abundance of larvae was found at station 10 in January (see Table 3). There was little consistency in seasonal variation in larval abundance between stations. This is partly due to the fairly small sample sizes, but also owing to the fact that different species, with different seasonal cycles, dominated the different station. However, when all stations and species are averaged, it is evident that fish larval abundance is generally higher between January-April (i.e. dry season; 140-205 larvae 1000 m⁻³) than during the rest of the year (42-139 larvae 1000 m⁻³).

There was a relatively clear spatial trend in fish larval abundance, with innermost, nearshore and shallow stations 3-8 having average densities of < ca.100 larvae 1000 m⁻³ and all the remaining more seaward stations experiencing densities > ca. 100 larvae 1000 m⁻³ (Table 3). Peak average concentrations occurred at the two most seaward stations (A & 10) with 303 and 194 larvae 1000 m⁻³, respectively.

**DISTRIBUTION OF PREDOMINANT FAMILIES**

Of the 48 families encountered during this study, 9 predominant families accounted for nearly 85% of all larvae and they occurred in sufficient abundance to warrant analysis at the family level. These were, in decreasing order of abundance: Sciaenidae (constituting 19.3% of all larvae collected), Leiognathidae (15.2%), Gobiidae (10.5%), Callionymidae (10.4%), Carangidae (7.5%), Engraulidae (6.7%),

Table 3. Concentration (no. 1000 m⁻³) of fish larvae in Phang-Nga Bay during 1984.

<table>
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<th>JUN</th>
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AVERAGE 205 140 171 158 95 139 102 42 119 63 50
Bregmacerotidae (6.5%), Cynoglossidae (6.2%) and Bothidae (2.0%). Of these, all but Gobiidae, Callionymidae and Bregmacerotidae are commercially important. Larvae of another six families of commercial fish species occurred in the bay. Altogether, larvae of the commercially important fish accounted for more than 60% of all larvae captured.

Seasonal abundance patterns varied considerably between families (Fig. 13). However, all but Leiognathidae showed a minor or a major peak during January-March and a low during May-September. Several families experienced an additional peak later in the year. In contrast, Leiognathidae showed a pronounced peak in July and relatively low abundance both early and late in the year.

**RELATIONS BETWEEN FISH LARVAL ABUNDANCE AND ENVIRONMENTAL VARIABLES**

Cluster analysis of larval abundance and taxonomic composition as well as environmental variables were carried out to investigate whether station groupings derived from fish larval and environmental data, respectively, showed any correspondence. However, differences between stations, both with respect to environmental variables and fish larval composition, were too small to produce consistent results by this method.

Instead, multiple regression analysis, with total fish larval abundance as dependent variable and selected environmental parameters

Fig. 13. Seasonal variation in the average concentrations (all stations, no. 1000 m$^{-3}$) of larvae on dominant families.
Table 4. Sign (+ or -) of regression coefficients in multiple regressions run for each month separately with fish larval concentration as dependent variable and secchi depth, salinity and concentration of chlorophyll-a as independent variables. Regression coefficients which are significant at the 5% level have been marked with an asterisk (*).

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as independent variables, was attempted (Table 4). In only a few instances were regression coefficients statistically significant, and the only reasonable consistent result was the positive relation between larval abundance and secchi depth (regression coefficient positive in 8 of 10 instances and statistically significant in 2 of 10 instances). Thus, fish larvae appear to be more abundant in clear than in turbid waters in Phang-Nga Bay.

**DISCUSSION**

Composition of the larval fish fauna

Phang-Nga Bay is an important nursery area for juvenile and larval fish. During this study, larvae of some 48 families were identified of which 12 abundant families contained species of commercial value. However, as a nursery ground for commercially important species the bay may be even more important than these figures indicate, since more than 60% of all larvae caught belonged to these 12 commercially important families.

Seasons in the plankton of Phang-Nga Bay

There was considerable variability in the measured environmental parameters between sampling occasions. However, to what extent this variability is related to seasonal events, in particular to the monsoon seasons, is less obvious. The expected pattern of increased nutrient availability and, hence, elevated primary production and phytoplankton biomass during the wet season is not really found in this study. Nutrient concentrations show little relation to precipitation and salinity, even though the spatial patterns of NO₃ distribution suggest that freshwater run-off via mangrove channels is a significant source of inorganic nutrients. Phytoplankton biomass (chlorophyll-a) and primary production also show little relation to nutrient concentrations and except for some stations during January-March, NO₃ and PO₄ appear not to be limiting primary production during most of the year.

Sundström et al. (1987), sampling a few stations in Phang-Nga Bay at weekly interval, found that primary production was, on average, somewhat higher during the wet than during the dry season, but also that variability within seasons and between stations was quite pronounced. In fact, simultaneous productivity measurements during one year at two stations separated by only a few kilometers, yielded production estimates that were only weakly intercorrelated ($t^2 = 0.27$, N=13, 0.10 < P < 0.05; Sundström et al., 1987, Tables 2 and 3). This suggests that a significant fraction of the observed variability is small scale (either temporal or spatial) rather than seasonal. Also, in their study there was little relation between precipitation and primary production. Furthermore, a study by Wium-Andersen
(1979) was unable to demonstrate any consistent seasonal pattern in primary productivity in Phang-Nga Bay. Thus, altogether these results suggest that in spite of a pronounced seasonal signal in precipitation and availability of NO₃ and PO₄, the response in phytoplankton production and biomass is weak, and the seasonality in phytoplankton is not very pronounced.

What, then, controls or limits phytoplankton production in Phang-Nga Bay? There are several possibilities: light, nutrients other than NO₃ and PO₄, and zooplankton grazing. It is unlikely that production is limited mainly by light availability; in that case one would expect a close relationship between secchi depth and primary production. This expectation is not borne out by the data (correlation between PP and secchi depth: $r^2 = 0.0$). It is possible that nutrients other than NO₃ and PO₄, for example silica, limits phytoplankton growth rate. Unfortunately, we have no measurements of silica concentrations in the bay waters. However, the net phytoplankton in the bay is entirely dominated by diatoms (Boonruang, 1985) and net phytoplankton contributes on average more than 40% of the primary production (Wium-Andersen, 1979). Thus, the availability of silica is crucial to overall primary productivity in the bay. Finally, the close correlation between primary production and chlorophyll-a concentration suggest that production is limited by phytoplankton biomass, that, in turn, may be controlled by zooplankton grazing. Thus, an element of top-down control (i.e. zooplankton grazing) of phytoplankton biomass and primary production in Phang-Nga Bay is hypothesized.

Boonruang (1985) investigated the seasonal variation in zooplankton in Phang-Nga Bay and on the basis of data from 7 sampling occasions during one year concluded that zooplankton biomass was somewhat higher during the dry (i.e. January-April) than during the wet season. However, here again, there was considerable within season variability, and the seasonal pattern was not very pronounced. However, elevated zooplankton biomass is consistent with lower phytoplankton production and biomass during the dry season, as observed in some years (Sundström et al., 1987), and top-down (zooplankton grazing) control of phytoplankton biomass and production. In conclusion, then, there seems to be some, although not very pronounced, seasonality in the plankton, and that the seasonal variation is controlled more by biological interactions than by physical processes.

Is there any consistent seasonal pattern in the abundance of fish larvae? Before discussing the seasonal patterns for the individual families, we shall treat the fish larvae as a group. Even though different families and species have different phenology (cf. Fig. 13), this approach is to some extent justified by the fact that the larvae of practically all species of marine fish occupy essentially the same food niche as microzooplankton feeders. Thus, everything else being equal, one would expect fish spawning seasons in general to be adapted to seasonally elevated availability of zooplankton to obtain highest possible feeding, growth and survival rates of their larvae. Even though the seasonal variation in food availability is small, there does in fact seem to be a consistent and significant pattern in the abundance of fish larvae in Phang-Nga Bay; average larval abundance between January-April is twice as high as average larval abundance during the rest of the year (169 vs. 87 larvae 1000 m$^{-3}$, $P < 0.05$, cf. Table 3). Thus, peak abundance of fish larvae coincide with peak abundance of zooplankton. Another important group of microzooplankton predators, chaetognaths, has its seasonal peak during the same period (Boonruang, 1985).

Since the seasonal signal in zooplankton concentration is weak it is not surprising that individual species and families have adopted quite different spawning seasons, as indicated by the diverse seasonal patterns between families (Fig. 13). In fact, none of the families shown in Fig. 13 reproduce the generalized seasonal pattern, most of them having several abundance peaks during the year. However, all but Leiogetnathidae do experience higher than average abundance between January-April. Whether the
the remaining part of the year. This appears to coincide with the period of maximum availability of zooplankton.

5) Individual families show quite diverse seasonal abundance patterns most, however, with above average concentrations in January-April.

6) The abundance and diversity of fish larvae increase towards the outer parts of the bay. This is attributed to (i) high turbidity in the inner parts of the bay, (ii) wash out of larvae from the innermost part of the bay, and/or (iii) influx of larvae from spawning grounds outside the bay.

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REFERENCES


Temporal and spatial distribution of fish larvae

several abundance peaks shown by many families reflect different, distinct unimodal spawning periods for different species within a family, several spawning periods during the year for the family as such, or are merely due to sampling variability cannot be decided from the available data. A much larger data base, including replicate sampling (to allow statistical treatment) and identification to species level would be required to address this question.

Spatial trends

There is considerable spatial along-bay variation in environmental variables in Phang-Nga Bay: turbidity, NO₃ concentration and chlorophyll all decline with direction from the inner to the outer parts of the bay while salinity shows an opposite trend (Fig. 9). Zooplankton concentrations and, hence, availability of food for fish larvae also decrease towards the outer parts of the bay (Boonruang, 1985). Yet, both abundance and diversity of fish larvae are lower in the inner bay than in the outer sectors. There are at least three possible and not mutually exclusive reasons for this pattern.

The multiple regression analysis of fish larval abundance versus environmental parameters quite consistently suggested that turbidity negatively affects fish larval abundance. Fish larvae are visual feeders. Since the perceptible distance in fish larvae is of the order of a few cm (e.g. Munk and Kristboe, 1985) and because secchi disc readings were in the order of meters, water transparency per se probably does not impact the feeding performance of the larvae. However, the larvae depend on light to seize their prey and in turbid water the light attenuates rapidly with depth, thus restricting larval feeding to the upper few meters of the water column. Therefore, the negative relation between larval abundance and water turbidity makes sense and may explain the lower abundance of larvae in the inner bay. A similar pattern was observed by Miller (1974) who found that fish larval abundance and diversity were reduced by some 75% and 55%, respectively in turbid as compared to clear water in nearshore, Hawaiian waters.

Due to fresh water runoff from tributaries entering the bay, net water flow is towards the outer parts of the bay. This will tend to "wash out" larvae from the innermost regions unless they possess some efficient mechanism of retention. Such mechanisms have indeed been described for fish larvae in tidal estuaries, where selective vertical migrations coupled to the tidal flow prevent the larvae from being washed out (e.g. Fortier and Leggett, 1982). To what extent such mechanisms are operative in Phang-Nga Bay is, however, unknown.

Not all larvae occurring in the bay have actually been spawned as eggs in the bay itself. Although many species of fish are known to spawn in the bay (such as gobids), many larvae are probably advected into the bay from offshore spawning areas. Of course stations in the outermost part of the bay will be more affected by influx of larvae from outside, and this mechanism may, therefore, explain the spatial trends in both larval diversity and abundance. This also points to the potential importance of Phang-Nga Bay as a nursery area for larvae and juveniles of fish that spend their adult life in the open Andaman Sea.

SUMMARY & CONCLUSIONS

1) Phang-Nga Bay is an important nursery area for fish larvae; more than 60% of the larvae caught in the bay belong to commercially important fish families.

2) The seasonal variation in phytoplankton biomass and productivity is not very pronounced in spite of pronounced seasonal variation in precipitation and concentrations of inorganic nutrients.

3) Phytoplankton production in Phang-Nga Bay appears to be controlled more by zooplankton grazing than by physical processes.

4) There is a consistent seasonal pattern in total fish larval abundance in Phang-Nga Bay, with concentrations during January-April being approximately twice as high as those in


