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Studies on eels and leptocephali in Southeast Asia: A new research frontier

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Abstract—Leptocephali are the unique type of fish larvae of eels and their close relatives, which are abundant in the upper few hundred meters of the world's tropical and subtropical oceans. Historically there have been few studies on leptocephali in Southeast Asia because these larvae require special fishing techniques to collect and are difficult to identify and match with their adult species. Recent cooperative sampling surveys for leptocephali in the Indonesian Seas region have indicated that there is a high biodiversity of eels in the region, so more taxonomic research to distinguish the many species of leptocephali of more than 20 families of eels and their relatives is needed to facilitate detailed studies on the biodiversity and ecology of these fishes. Several techniques such as fishing large plankton nets offshore or using set nets in coastal areas with strong tidal flow can be used to collect leptocephali, and a new field guide to identifying the major taxa of leptocephali in the region has been recently published. Examination of metamorphosing larvae entering coastal areas is one method to help match larval and adult forms, and a more modern technique is to compare molecular genetic characters between larval and adult specimens, but this requires the collection and proper tissue preservation of both leptocephali and adults. These types of studies and those on the ecology of eels and their larvae represent a new research frontier in marine biodiversity science in Southeast Asia, which is the center of marine biodiversity worldwide.

Key words: leptocephali, eels, sampling methods, identification, biodiversity

Introduction

Progress in understanding the life history and biology of leptocephali began after early naturalists first realized that these unusual marine organisms were actually the larval form of eels. They differ so dramatically from the adult form of eels that they were thought to be a completely separate type of marine fish for almost a century, until in the late 19th century when it was finally determined that leptocephali were actually the larval form of eels (Smith 1989a). Their unique characteristics include a laterally compressed, transparent body that is filled with a gelatinous material used for energy storage and an unusually large size increase before metamorphosis (Castle 1984, Hulet and Robbins 1989, Smith 1989a, Pfeiler 1999). They also differ from other types of fish larvae because they only have a thin layer of muscle tissue that overlays the gelatinous material, which enables their bodies to be completely transparent when they are alive. This type of body results in unique physiological characteristics such as very low metabolic rates (Pfeiler 1999) and the ability to swim both forwards and backwards in an anguilliform locomotion style (Miller and Tsukamoto 2004).

Only elopomorph fishes of the orders Anguilliformes, Saccopharyngiformes, Albuliformes, and Elopiformes have leptocephalus larvae (Inoue et al. 2004), and the biology and physiology of these transparent and fragile larvae is poorly known because they rarely stay alive when captured in nets. The eels of the Anguilliformes are the most common species that have this type of larva, but the secretive and typically nocturnal behavior of most species of marine eels has made it difficult to learn much about their life histories. Because of this, the long larval duration of their leptocephalus larvae makes sampling surveys for leptocephali a useful way to learn about the biodiversity and reproductive ecology of eels in each region of the world.

Recent surveys for leptocephali in the Indonesian Seas have indicated that there is a high biodiversity of marine eels in the Southeast Asia region compared to other areas (Minagawa et al. 2004, Wouthuyzen et al. 2005), so it is a good place to conduct studies on leptocephali and the ecology of eels. In addition, more species of the catadromous freshwater eels of the genus *Anguilla* live in this region than anywhere else in the world (Ege 1939, Watanabe 2003). Parts of Southeast Asia almost certainly have the highest biodiversity of marine fishes in the world (Randall 1998, Carpenter and Springer 2005), and many species of marine eels have been recently reported from coral reef areas in Indonesia (Allen and Adrim 2003). This region likely has such high marine biodiversity because it has many coral reef areas (Fig. 1) that are separated by deep basins and large islands, and it is bordered by the western North Pacific (WNP) and Indian oceans

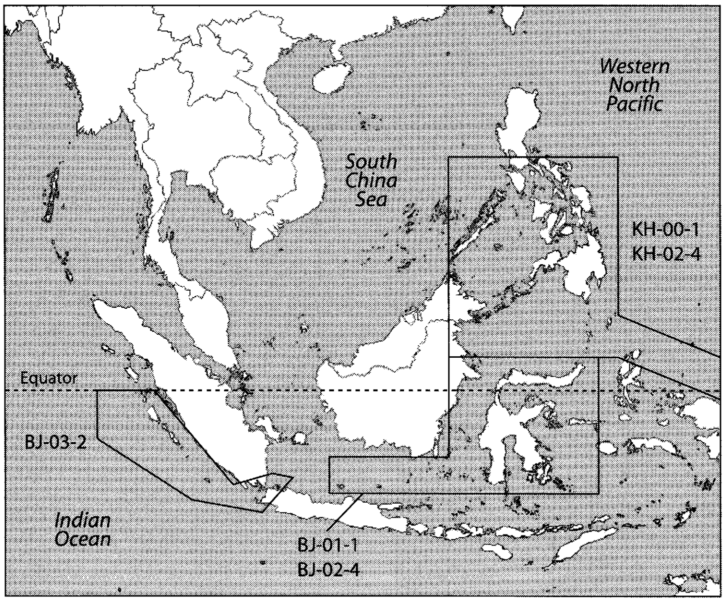

Fig. 1. Map of the Southeast Asia region showing the general areas where leptocephali were collected during five sampling surveys conducted by the R/V Hakuho Maru (KH-00-1, KH-02-4) and the R/V Baruna Jaya (BJ-01-1, BJ-02-4, BJ-03-2) between 2000 and 2003 (see Table 1). The locations of coral reefs or small islands throughout the region are shown by black dots. This distribution of coral reefs was adapted from maps obtained from the ReefBase project (http://www.reefbase.org; NASA and NOAA, USA; see Stumpf et al. 1999).

on either side. The Southeast Asia region also includes the boundaries of several lithospheric plates (Philippine, Pacific, Australian, Indian, and Eurasian plates) and so the high biodiversity of marine fishes and corals is thought to be the result of its unique geological and evolutionary history in combination with the wide variety of habitats associated with its many islands and coral reef areas (Randall 1998, Briggs 1999, Edinger et al. 2000, Hughes et al. 2002, Allen and Adrim 2003, Carpenter and Springer 2005).

Many species of marine eels are known to inhabit coral reef areas (Böhlke 1989a, Allen and Adrim 2003), but there are other taxa of eels that are found in a wider range of habitats, such as the continental slope and the mesopelagic zone of the open ocean (Castle 1984, Böhlke 1989a). Some marine eels such as garden eels and moray eels appear to spawn in their shallow water adult habitats without any migration (Moyer and Zaiser 1982, Thresher 1984, Ferraris 1985), whereas others appear to spawn somewhere over or near the edge of the continental shelf, but not in offshore waters (Castle 1979, Miller 1995, Miller et al. 2002a, Kimura et al. In press). In contrast, a few species of congrids appear to make migrations to spawn in offshore areas (McCleave and Miller 1994, Miller 2002). The catadromous anguillid eels also migrate from their freshwater or estuarine habitats to spawn in the open ocean (Tsukamoto 1992, McCleave 1993, Aoyama et al. 2003), and mesopelagic eels spawn in the open ocean possibly without any migration (Castonguay and McCleave 1987a, Wippelhauser et al. 1996).

Despite their adults living and spawning in different areas, their leptocephali can all be collected together in the upper few hundred meters of the ocean (Castonguay and McCleave 1987b, Kajihara et al. 1988), where they live during their larval period. During this time period they may grow fairly rapidly (Bishop et al. 2000, Ishikawa et al. 2001, Ma et al. 2005, Kuroki et al. In press), although their feeding ecology is still poorly understood (Mochioka and Iwamizu 1996, Otake et al. 1993). After larval durations from several months to possibly as much as a year in some cases (Arai et al. 2001, Marui et al. 2001, Kuroki et al. In press), each species undergoes the process of metamorphosis and changes into the drastically different glass eel or elver stage. The transition-stage glass eels then recruit back to their respective juvenile and adult habitats in freshwater or estuarine areas in the case of anguillid eels, shallow coastal areas in the case of the "shelf" species (Chlopsidae, Congridae, Moringuidae, Muraenidae, Ophichthidae), deeper regions of the continental shelf or abyssal plane in the case of "slope" species (Nettastomatidae, Synaphobranchidae), or the mesopelagic zone in the case of "oceanic" species (Derichthyidae, Nemichthyidae, Serrivomeridae). Because leptocephali can often be abundant in some regions of the worlds oceans (Castonguay and McCleave 1987a, Tsukamoto 1992, Miller and McCleave 1994, Miller et al. 2002a), large numbers of metamorphosing leptocephali and glass eels likely recruit back to a variety of habitats. These recruits may be a significant source of carbon transport from the surface layer of the ocean to other areas and they may be important ecological components of the ecosystems where they recruit.

The Southeast Asia region contains all of the different types of habitats used by eels, and has large areas of shallow continental shelf, deep basins and steep slopes leading up to many islands or larger landmasses that are surrounded by tropical coral reef and other habitats. Because of the likely high biodiversity of marine and freshwater eels in this region (see Böhlke 1989a, Allen and Adrim 2003), it is important to learn about the species composition, biology, and possible ecological importance of eels, their leptocephali, and their larvae that recruit back to coastal areas, to help gain a greater understanding of these critically important marine and freshwater ecosystems. In this paper we overview research on eels and their leptocephali in Southeast Asia, outline the methodology for studying leptocephali, and identify important research subjects that can be pursued in this region of the world where very little is known about these mysterious and likely important components of the marine and freshwater environments.

Studies on eels and leptocephali in Southeast Asia

The Carlsberg's Around the World Expedition was the first major effort to collect leptocephali in the waters of the Southeast Asia region (Jespersen 1942). Collections of leptocephali were made along the margin of the WNP, in the Indonesian Seas, and in the South China Sea from March to April in 1929 (Fig. 2). Relatively large sized anguillid leptocephali were collected at a number of stations along the northeast edge of New Guinea and in the Indonesian Seas and these catches were reported on by Jespersen (1942). Greater catches of anguillid leptocephali were made off west Sumatra where a wide range of sizes of leptocephali were collected (see Miller 2003), indicating that a spawning area of anguillid eels was located in the region (Jespersen 1942). However, other than a few reports including some specimens of a few taxa of leptocephali collected during these surveys (Smith and Castle 1982, Castle 1997), the data on most of the other taxa of leptocephali collected in Southeast Asian waters were never published.

More recently, there have been several sampling surveys for leptocephali in the region (Fig. 1) that have collected large numbers of leptocephali (Table 1), which included some anguillid leptocephali. Three of these surveys were cooperative efforts between scientists primarily in Japan and Indonesia that sampled for leptocephali using the R/V Baruna Jaya VII. There were five different species of anguillid leptocephali collected during these surveys, whose distribution and size ranges have provided evidence that some species of tropical anguillids have relatively short spawning

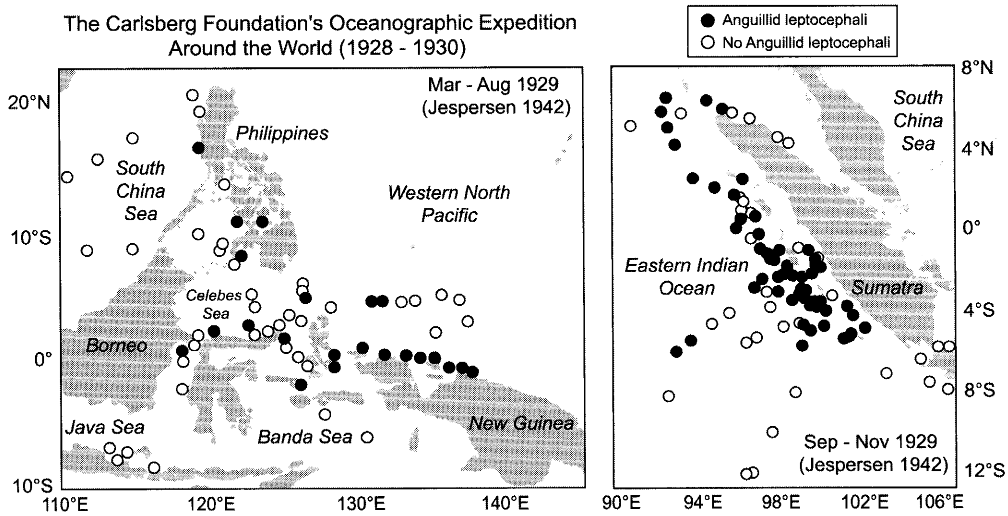

Fig. 2. Maps of the sampling stations and locations were anguillid leptocephali were collected in the Southeast Asia region during the Carlsberg's Around the World Oceanographic Expedition.

Table 1. Descriptions of the five sampling surveys for leptocephali that have been made in various regions of Southeast Asia in recent years by the R/V Hakuho Maru (KH-) of the University of Tokyo and the R/V Baruna Jaya VII (BJ-) of the Indonesian Institute of Science (LIPI) between 2000 and 2003.

Cruise	Region	Dates	Number of stations	Number of tows	Number of leptocephali
KH-00-1	Celebes, Sulu seas	16–27 Feb 2000	32	56	3,201
KH-02-4	Celebes, Sulu seas	14 Nov–9 Dec 2002	21	25	2,595
BJ-01-1	Around Sulawesi Isl.	12–26 May 2001	25	46	2,575
BJ-02-4	Around Sulawesi Isl.	27 Sep–16 Oct 2002	33	65	2,374
BJ-03-2	Off west Sumatra	5–21 Jun 2003	26	51	2,811

migrations, and that some species have more than one spawning area (Aoyama et al. 2003). There have also been studies of the age, growth and hatching dates of their leptocephali (Kuroki et al. In press). The short migrations and apparently wide range of spawning times indicated by these studies have shown that tropical anguillid eels differ considerably from the their temperate relatives, which have much longer spawning migrations to spawn far out in the open ocean (see Tsukamoto 1992, McCleave 1993).

There have also been several studies on the glass eels of tropical anguillid eels that recruit to various parts of Southeast Asia. These studies have found that glass eels recruit to different areas of Indonesia to some degree throughout the year (Setiawan et al. 2001, Sugeha et al. 2001, Budimawan and Lecomte-Finiger 2005). Various studies have also used the otolith microstructure of tropical glass eels to estimate their ages (e.g. Arai et al. 1999, 2001, 2002, 2003, Marui et al. 2001). Consistently younger larval durations of *Anguilla celebesensis* glass eels (Arai et al. 2001) have confirmed that this species appears to have a short-distance spawning migration, and the longer larval duration of *A. marmorata* glass eels, support the hypothesis that this species spawns in the North Equatorial Current region and then recruits to a variety of areas along the southeast margin of the WNP (Aoyama et al. 1999, Miller et al. 2002b, Ishikawa et al. 2004). Other studies have aged the glass eels of *A. bicolor bicolor* from southwest Java Island (Arai et al. 1999, Setiawan et al. 2001), which were born in the eastern Indian Ocean. There have also been some initial studies on the age, growth and downstream migration of tropical eels on Sulawesi Island (Sugeha 2003), but more research is needed to understand the life history and ecology of tropical anguillids in the Southeast Asia region.

In addition to studies on anguillid leptocephali and glass eels, there have been some studies on many other species of leptocephali collected during the surveys listed in Table 1 and other collections. The distribution and species richness of all families of leptocephali in small collections of leptocephali made in a number of different regions of the Indonesian Seas has been reported (Miller et al. 2002c). Minagawa et al. (2004) directly compared the characteristics of the species assemblages of leptocephali collected during the 2001 (BJ-01-1) survey around Sulawesi Island (Table 1) to a similar survey in the East China Sea. This analysis found that there was a much higher species diversity and catch rates of some taxa of leptocephali in the Indonesian Seas than in the East China Sea. Wouthuyzen et al. (2005) then examined the biodiversity and catch rates of each taxa of leptocephali collected during the 2001 survey around Sulawesi Island. The assemblages of leptocephali around Sulawesi Island in the 2001 and 2002 (BJ-02-4) surveys were also reported by Minagawa and Miller (2005) to be relatively similar, suggesting the possibility that some eels in these tropical areas probably spawn throughout the year. However, further research at the species level will be required to determine this, because very little is known about the seasonality of spawning of most marine eels in general (Thresher 1984). There is also evidence that families such as the Muraenidae have a variety of gonadal morphologies (Fishelson 1992), so marine eels in Southeast Asia may have wide range of reproductive strategies.

Techniques for collecting leptocephali

Leptocephali can be collected by a variety of plankton nets or midwater trawls, but the size of the net and the timing and style of fishing are essential factors to enable large numbers to be collected. The large body size and prominent eyes of leptocephali and their ability to swim both forwards and backwards (Miller and Tsukamoto 2004), apparently make leptocephali well adapted for avoiding small sized plankton nets or even large trawls during the day (Castonguay and McCleave 1987b, Miller and McCleave 1994). Therefore, large mouth opening nets or trawls that are fished at night must be used to collect leptocephali in the open ocean.

The most widely used trawl for collecting leptocephali in recent years has been the Isaacs Kidd Midwater Trawl (IKMT) (Fig. 3). This trawl has been used in surveys for leptocephali in the western North Atlantic (WNA), Pacific, and eastern Indian Ocean in recent decades in surveys targeting anguillid and other leptocephali (e.g. Tsukamoto 1992, McCleave 1993, Aoyama et al. 1999, 2003, Miller et al. 2002a, b, Kuroki et al. In press). Fishing the IKMT with a mouth opening of 8.7 m^2 and 0.5 or 1.0 mm mesh at night, has been found to be a successful way to collect all sizes of leptocephali. Comparisons between oblique or step tows of the IKMT at night showed that both methods appeared to be effective ways of collecting leptocephali in the Indonesian Seas region (Wouthuyzen et al. 2003), but the amount of time fishing in the upper 100 m is likely the key factor. Other types of nets, such as with large rectangular or hexagonal frames have been used to collect leptocephali (Kajihara et al. 1988), and the MOCNESS-10 (Fig. 3) with a 10 m^2 mouth opening (Weibe et al. 1985) is also very effective at catching large sized leptocephali (Miller 1995, 2002). Large sized ring nets (Fig. 3) have also been used with mouth diameters of 2–3 m (Castonguay and McCleave 1987b).

Another way to collect leptocephali has become apparent from studies of fish larvae recruiting back to coral reef or shallow coastal areas. Research on the recruitment of fish larvae to the Great Bahama Bank using floating channel nets anchored to the bottom (Fig. 4), which fished at the surface or at a depth of 2 m (Shenker et al. 1993) have collected large numbers of leptocephali. These leptocephali were apparently being transported onto the shelf primarily during flood tides (Thorrold et al. 1994a). Most were caught at night and they were more abundant at the surface (Thorrold et al. 1994a, b).

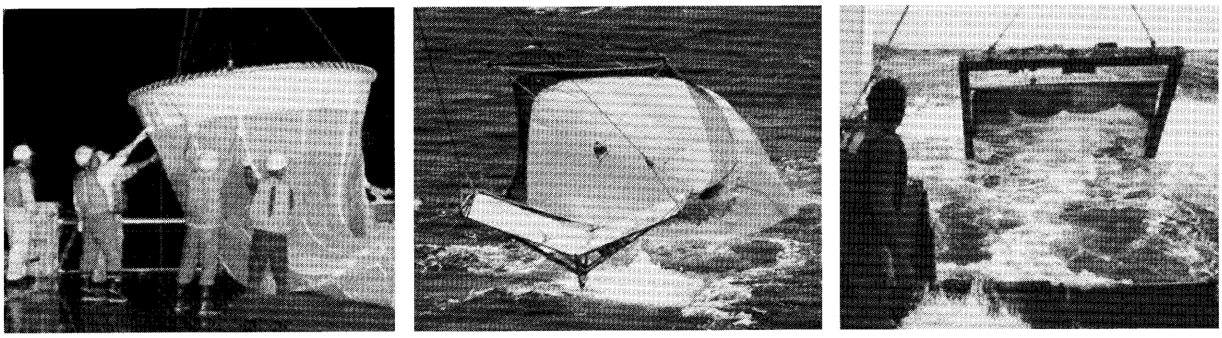

Fig. 3. Three types of large mouth opening midwater trawls or ring nets that have been used to collect leptocephali. A 7.1 m^2 mouth opening ORI net (left), an 8.7 m^2 Isaacs Kidd Midwater Trawl (IKMT), and the 10 m^2 MOCNESS-10 multiple opening and closing net and environmental sensing system (right).

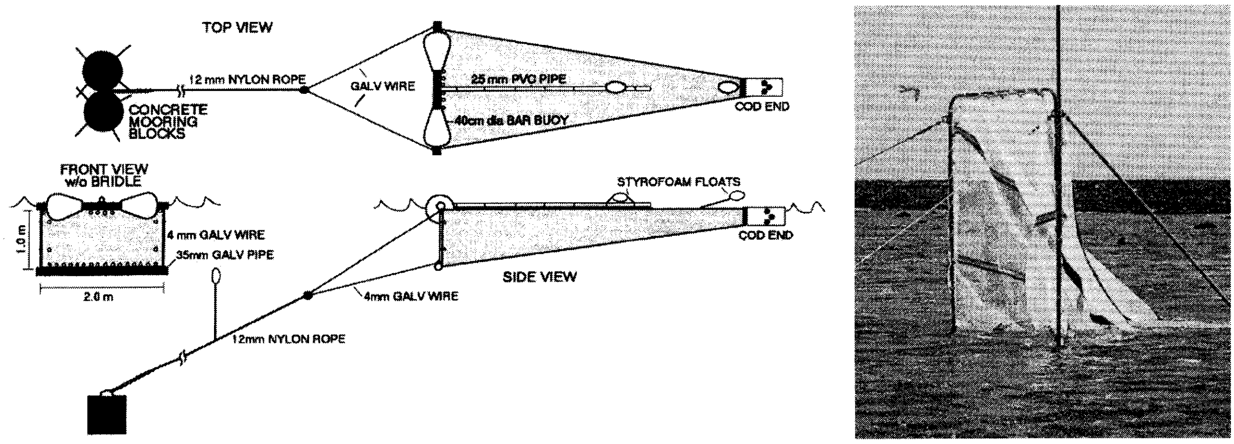

Fig. 4. A diagram of a channel net from Shenker et al. (1993) that was fished at the surface or a depth of 2 m on the Great Bahama Bank adjacent to Exuma Sound in the northern Bahamas (left), and a photograph of a set net from Doherty and McIlwain (1996) on a coral reef area of Australia (right). Both types of nets collected leptocephali moving onto the shelf or into coral reef areas on flood tide.

There was also clear evidence of lunar or semi-lunar periodicity in their catches (Thorrold et al. 1994a, c), which can be seen in the catches of leptocephali of the family Ophichthidae recruiting to the Great Bahama Bank from June to September (Fig. 5).

Similar studies on fish larvae using set nets have collected leptocephali as they recruit onto fringing reef areas in the Indo-Pacific region. These nets were fixed on the outer reef crest in specific areas with strong unidirectional flow onto the reef (Fig. 4) and have been used to study the movements of fish larvae onto reefs in French Polynesia (Dufour and Galzin 1993, Dufour et al. 1996) and Australia (Doherty and McIlwain 1996, McIlwain 2003). Some of these studies reported catching large numbers of leptocephali (Dufour et al. 1996, McIlwain 2003), so these techniques could be used to collect leptocephali at certain locations in coral reef areas in Southeast Asia where there is strong tidal flow that could carry leptocephali onto the reef.

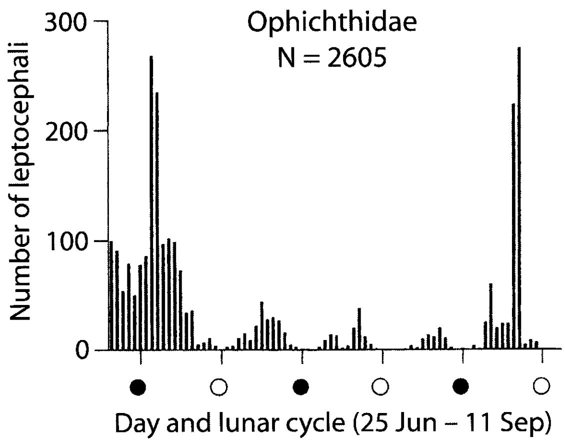

Fig. 5. A plot of the catches of leptocephali of the family Ophichthidae collected by channel nets over the Great Bahama Bank adjacent to Exuma Sound in the northern Bahamas that was modified from Thorrold et al. (1994a).

Identification of leptocephali

Because the body forms of leptocephali differ so much from the juvenile and adult eels, it is very difficult to match leptocephali with their adult forms. The greatest progress in doing this has been in the WNA where most of the commonly collected leptocephali have been matched with their adult species (Böhlke 1989a, b). In comparison, there has been relatively little effort to match species of eels with their leptocephali in the Indo-Pacific region. Many of the species of the congrid subfamily Bathymyrinae, which includes the genus *Ariosoma*, have been described (Mochioka et al. 1982, 1991), but few of these species have been matched with adult species. The species or types of leptocephali collected around Japan have been described (Tabeta and Mochioka 1988), a few congrid species of the garden eels of the subfamily Heterocongridae have been recently matched with their adult species (Castle 1997), and nettastomatid leptocephali have been studied (Smith and Castle 1982). However, the other large families or subfamilies such as the Muraenidae, Ophichthidae, and the congrid subfamily Congrinae have not been studied yet, which presently makes it difficult to match the majority of leptocephali to a species or even a known type of leptocephalus.

Various characters such as body shape, length and shape of the gut, and pigmentation can be used to identify leptocephali or separate them into different types (see Böhlke 1989a, Miller and Tsukamoto 2004). Using these techniques, more than 130 species or types of leptocephali were distinguished during a survey for leptocephali around Sulawesi Island of Indonesia (Wouthuyzen et al. 2005). Families such as the Congridae and Ophichthidae had the most apparent species in these collections. The leptocephali of the Ophichthidae are especially difficult to separate into different types because of the wide range of characters that must be used to distinguish all the different types (Leiby 1979, 1984, 1989). The three general types or subfamilies of ophichthid leptocephali can be distinguished relatively easily (Leiby 1989, Miller and Tsukamoto 2004), but many characteristics such as the number of gut swellings, position of the last vertical blood vessel, location of the dorsal fin, and types and amount of pigmentation must be examined before they can be separated into different species (Fig. 6). This diversity of characters makes it possible to separate the different species, as has been done for ophichthid leptocephali in the WNA (Leiby 1989). Alternatively, families such as the Muraenidae have relatively few larval characters to separate different species of leptocephali and the larvae of several adult species may be included in some of the different species or types of leptocephali that have been described in the WNA (Smith 1989b).

Based on this set of circumstances, a new book has been published that uses a mostly pictorial approach to explaining how to separate collections of leptocephali into different types or species (Miller and Tsukamoto 2004). Certain criteria are explained that can be used to separate leptocephali into the major families found in the Southeast Asia region and then other patterns of gut shape, pigmentation, or number of myomeres as mentioned above can be used to distinguish different species or types. Studies that begin to distinguish the different types of leptocephali within each family are a useful first step to prepare for matching the larvae to the adult species that are known in the region.

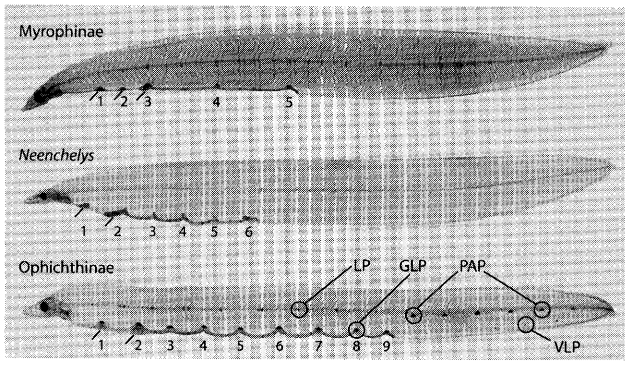

Fig. 6. Photographs of leptocephali of the three main groups of the family Ophichthidae showing some of the key characters used to separate the different species or types of leptocephali in the Indo-Pacific region. The Myrophinae and Ophichthinae are the two known subfamilies, but the *Neenchelys* type leptocephali have characteristics of both subfamilies (Castle 1980, Leiby 1984). The liver lobes are indicated by short slanted lines, the gut loops are numbered, and lateral pigment (LP), gut loop pigment (GLP), postanal pigment (PAP), and ventrolateral pigment (VLP) spots are labeled. From Miller and Tsukamoto (2004).

Methods of preserving leptocephali

Leptocephali are somewhat difficult to preserve for long-term storage (Smith 1989a), possibly because of their unusual internal body composition of large amounts of gelatinous energy storage material. This transparent substance is composed mostly of various lipid and glycosaminoglycan compounds (see Pfeiler 1999), which may break down or dissolve during long-term preservation. Various problems have been observed in long-term preservation in formalin or in alcohol solutions (Smith 1989a), but for short-term research objectives, a choice between formalin or ethanol must be made based on how the specimens will be used. If a specimen will be used for otolith or genetic analysis, it must be preserved in 95–99% ethanol. However, leptocephali preserved in this high concentration of alcohol quickly lose their body shape and shrivel up because the internal gelatinous material apparently dehydrates or breaks down in the high concentration alcohol. Therefore, to preserve a specimen for later morphological analysis, it must be preserved in formalin.

This means that a decision must be made on board the ship or upon capturing any leptocephalus, about how it will be examined and preserved. For morphological specimens, leptocephali should be preserved in a 4–10% formalin-seawater solution. One strategy is to preserve them in a 10% solution in the field to ensure quick fixation while being laid flat in a tray, and then transfer them later to a lower concentration of 4–7% formalin later in the laboratory. Specimens to be used for otolith or genetic studies should be first examined to collect their morphological data needed for identification and then preserved in 95–99% ethanol. These specimens will lose their body shape, so it is necessary to make morphological examinations before preservation if possible. For long-term archival specimens, it is possible however, that even formalin preserved specimens should be transferred to 70% ethanol because they may eventually break down or lose pigment in formalin solutions (Smith 1989a).

Methods of matching larvae and adults

One of the fundamental problems in research on leptocephali and the reproductive ecology of eels has been the difficulty in matching the larvae with their adult form. Because the body forms, pigmentation patterns and even relative body sizes have no correlation between leptocephali and the juveniles and adults, it is essentially impossible to match the two forms without careful research. In some cases in regions of the world where the eel fauna is fairly well known, unusual species that have a much higher or lower range of myomeres and vertebrae can be matched by exclusion of other possibilities. This is typically unusual though, because most large families such as the Congridae, Muraenidae, and Ophichthidae have many species whose number of vertebrae overlap too much to be able to use this character alone to match leptocephali to the adult species (Böhlke 1989a, b).

In these cases, other techniques such as using the transitional forms of metamorphosing leptocephali or early stage glass eels have been used to link the larvae and adults (Smith 1989a). Metamorphosing leptocephali or glass eels often retain some pigmentation features of their larval forms while developing external morphological features of their adult species. This enables a match to be made by comparing the morphological features and the myomeres and vertebrae of the two forms. Without excellent knowledge of the morphology of both forms however, this technique is likely to be very difficult and will require the accumulation of reference collections of juvenile and adults that can be compared to the transitional forms when they are collected. The best way to use this technique is to keep some of the metamorphosing leptocephali alive in aquaria and see what type of eel they metamorphose and grow into.

The third and most advanced way to match leptocephali with adult species is to build a reference database of genetic sequences of adults that can be compared to the sequences of leptocephali as they are collected. Studies can be initiated in a particular region to collect juvenile and adult eels in conjunction with offshore collections of leptocephali or the capture of leptocephali as they recruit to coastal or coral reef areas. Genetic identification has been used in recent years to identify anguillid leptocephali (e.g. Aoyama et al. 1999, 2003) using the mitochondrial 16S ribosomal RNA region and these techniques can be applied to marine eel species. This concept of developing a DNA database of each species to use for identifying specimens has been discussed recently and has been referred to as using DNA taxonomy or DNA "barcodes" (e.g. Herbert et al. 2003, Tautz et al. 2003). For eels, it could be a very useful tool, but will require extensive efforts to collect and properly identify specimens for use as the representative genetic sequences for each species. Juvenile and adult marine eels of most species are not particularly easy to collect, but some likely can be caught by divers at night or using baited traps. Once a variety of adult species have been collected and tissue samples analyzed, leptocephali that are collected can be analyzed and compared to see which adult sequences they match.

Perspectives on eel studies in Southeast Asia

A new era in studies on leptocephali has begun in Southeast Asia that can include a variety of types of research projects to learn about these larvae and about their poorly known juveniles and adults. The five recent surveys for leptocephali made in recent years in several offshore areas of the region indicate that eels may be very abundant throughout most of Southeast Asia and that their role in these important marine ecosystems needs to be better understood. These initial surveys are only a starting point for studies on the life history, ecology, and identification of eels and their larvae however, because studies are also needed closer to shore where many marine eels probably spawn. Sampling using large ring nets or rectangular nets close to the shelf break and using set nets in areas of strong tidal currents can provide valuable new data about the spawning and recruitment patterns of eels in each particular area throughout Southeast Asia. Studies on the freshwater ecology of yellow eels and the timing downstream migrations of reproductively maturing silver-phase anguillid eels are also needed to learn more about the various species that live in the region. Efforts to collect juvenile and adult freshwater and marine eels for documenting species ranges and for obtaining genetic samples for matching the larvae and adults are also critically important for advancing our knowledge about these secretive and often mysterious fishes.

Eels are a poorly known fauna worldwide, but in Southeast Asia it is possible that they have much higher species diversity than most other areas and may be important and mostly unrecognized components of marine ecosystems throughout the region. Therefore we hope that the concepts presented in this paper and the recent publication of the basic methods for identifying leptocephali (Miller and Tsukamoto 2004), will facilitate a variety of studies in this new research frontier to learn about these widespread but rarely seen marine fishes and their unusual larvae.

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