JOURNAL OF CRUSTACEAN BIOLOGY, 23(4): 963–973, 2003

MARINE ORNAMENTAL DECAPODS—POPULAR, PRICEY, AND POORLY STUDIED

Ricardo Calado, Junda Lin, Andrew L. Rhyne, Ricardo Araújo, and Luís Narciso

(RC, LN) Laboratório Marítimo da Guia—Faculdade de Ciências da Universidade de Lisboa, Departamento de Biologia Animal, Estrada do Guincho, 2750-642 Cascais, Portugal (rjcalado@hotmail.com; lnarciso@fc.ul.pt); (JL, ALR) Department of Biological Sciences, Florida Institute of Technology, 150 W. University Boulevard, Melbourne, Florida 32901, U.S.A. (jlin@fit.edu; arhyne@fit.edu); (RA) Estação de Biologia Marinha do Funchal, Cais do Carvão, Promenade da Orla Marítima do Funchal, Gorgulho, 9000-107 Funchal, Madeira, Portugal (ricardo.araujo@mail.cm-funchal.pt) (corresponding author (RC): rjcalado@hotmail.com)

ABSTRACT

The growing demand for highly priced marine ornamental species has contributed to the endangered status of coral reefs. A list of 128 of the most heavily traded marine ornamental decapod crustacean species is tabulated. The development of commercial culture techniques, the knowledge of the larval development, and the association with vertebrate and invertebrate organisms are presented for these species. Forty-nine of the species are caridean shrimp, with the Hippolytidae family alone accounting for 15. Anomuran and brachyuran crabs are the next most traded groups (32 and 27 species, respectively), with the pricey stenopodidean shrimp, Astacidea, and Palinura lobsters being represented by a considerably lower number of species (7, 7 and 6, respectively). The main bottlenecks impairing the commercial culture of ornamental shrimp and lobsters are their long larval development and poor survival rates. The main constraint for the development of culture techniques for hermit and brachyuran crabs is their low commercial value. The ecological impacts of harvesting ornamental species are still poorly studied. Nevertheless, the collection in considerable numbers of hermit and small majid crabs (e.g., *Clibanarius* and *Mithraculus*) from tidal areas, fish cleaning shrimp (e.g., *Lysmata* and *Stenopus*), and the crown-of-thorns sea star eaters *Hymenocera*, is likely to have serious impacts on the ecosystem. The cooperation between researchers working on larval biology, population dynamics, ecology, aquaculture, and fisheries is essential to properly manage the collection of marine ornamental decapods.

In recent years, considerable efforts have been focused on the minimisation of negative impacts caused by the harvest of marine ornamental species from the wild (Wood, 2001). Nevertheless, the marine segment of the aquarium trade industry still predominantly relies on wild collected specimens, with over 90% of the traded species being taken from coral reefs (Tlusty, 2002). The growing demand of highly priced marine ornamentals has contributed to the endangered status of certain groups such as syngnathid fishes, stony corals, and giant clams (Bruckner, 2001).

Although fishes and corals are still the most heavily traded ornamental marine species for the aquarium, many decapod species are also highly popular among hobbyists. In addition, a few freshwater decapods have also been recently targeted by the aquarium trade (Lukhaup, 2002): species of *Caridina* H. Milne Edwards, 1837; *Neocaridina* Kubo, 1938; and *Cherax* Erishson, 1846. Marine decapods receive the "ornamental status" mainly because of their dazzling coloration and delicacy, hardiness in captivity, and by being "reef safe" (they do not harm other aquarium organisms, see Sprung, 2001). Nevertheless, if a species presents mimetic adaptations, displays associative behaviour (particularly fish cleaning and symbiotic association), or performs a specific function on the reef aquarium (such as eating nuisance organisms), it may also be targeted by the marine ornamental industry.

The efforts on conservation and management of decapod crustaceans have long been entirely focused on crustacean fisheries for human consumption. However, once ignored crustacean species are now highly valued resources, commending high market prices in the aquarium industry. The growing awareness on the pres-

Table 1. Distribution, commercial culture techniques (CCT) (established, E; being developed, BD; not addressed, NA), larval development (LD) (known, K; partially known, PK; unknown, U), and associative behaviour (AB) (associated with invertebrates, AI; associated with fish, AF; fish cleaners, FC) of the most popular marine ornamental caridean shrimp in the aquarium trade industry.

Scientific name	Distribution	CCT	LD	AB
Alpheidae				
Alpheus armatus	Western Atlantic	NA	U	AI
Alpheus bellulus	Indo-west Pacific	NA	U	AF
Alpheus bisincisus	Indo-Pacific	NA	U	–
Alpheus djeddensis	Indo-west Pacific	NA	U	AF
Alpheus lottini	Indo-west Pacific	NA	PK[4]	–
*Alpheus macrocheles**	Eastern Atlantic	NA	K[5]	–
Alpheus ochrostriatus	Indo-west Pacific	NA	U	AF
*Alpheus glaber**	Eastern Atlantic	NA	K[5]	–
Alpheus randalli	West Pacific	NA	U	AF
Hippolytidae				
Lysmata amboinensis	Indo-Pacific	BD	PK[6]	FC
Lysmata californica	Eastern Pacific	BD	U	FC
Lysmata debelius	Indo-Pacific	BD	U	FC
*Lysmata grabhami**	Atlantic	BD	U	FC
Lysmata kuekenthali	Indo-west Pacific	NA	U	–
Lysmata rathbunae	Western Atlantic	E[1]	U	–
*Lysmata seticaudata**	Eastern Atlantic	E[2]	PK[7]	FC
Lysmata wurdemanni	Western Atlantic	E[1]	PK[8]	–
Lysmata vittata	Indo-Pacific	NA	U	–
Parhippolyte uveae	Indo-Pacific	NA	U	–
Saron inermis	Western Pacific	NA	U	–
Saron marmoratus	Indo-Pacific	NA	U[9]	–
Saron neglectus	Western Pacific	NA	U	–
Saron rectirostris	Western Pacific	NA	U	–
*Thor amboinensis**	Circumtropical	BD	U	AI
Gnathophyllidae				
Gnathophyllum americanum	Circumtropical	NA	PK[10]	AI[14]
Gnathophyllum elegans	Eastern Atlantic	NA	U	AI[14]
Hymenoceridae				
Hymenocera elegans	Indo-Pacific	NA	U	–
Hymenocera picta	Eastern Pacific	E[3]	K[3]	–
Palaemonidae				
Allopontonia iaini	Indo-west Pacific	NA	U	AI
*Periclimenes aegylios**	Mediterranean	NA	PK[11]	AI
*Periclimenes amethysteus**	Mediterranean	NA	PK[11]	AI
Periclimenes brevicarpalis	Indo-Pacific	NA	U	AI
*Periclimenes granulatus**	Mediterranean	NA	PK[11]	AI
Periclimenes holthuisi	Indo-Pacific	NA	U	AI
Periclimenes lucasi	Eastern Pacific	NA	U	AI
Periclimenes pedersoni	Western Atlantic	NA	U	AI
*Periclimenes sagittifer**	Eastern Atlantic	BD	PK[12]	AI
Periclimenes yucatanicus	Western Atlantic	NA	U	AI
Stegopontonia commensalis	Indo-Pacific	NA	U	AI
*Tuleariocaris neglecta**	Eastern Atlantic	NA	U	AI
Urocaridella antonbruunii	Indo-west Pacific	NA	U	FC
Rhynchocinetidae				
Cinetorhynchus concolor	Western Pacific	NA	U	–
Cinetorhynchus hiatti	Indo-Pacific	NA	U	–
Cinetorhynchus hendersoni	Pacific	NA	U	–
Cinetorhynchus manningi	Western Atlantic	NA	U	–
*Cinetorhynchus rigens**	Eastern Atlantic	BD	K[13]	–
Rhynchocinetes durbanensis	Indo-Pacific	NA	U	–
Rhynchocinetes serratus	Western Pacific	NA	U	–
Rhynchocinetes uritai	Western Pacific	NA	U	–

* Marine ornamental decapod species occurring in European warm temperate and subtropical waters. [1] Zhang *et al*., 1998a; Lin, 2000; [2] Calado *et al*., 2003; [3] Fiedler, 1994. [4] Al-Kholy, 1960; [5] Lebour, 1932; [6] Wunsch, 1996; [7] Caroli, 1918 (from plankton); [8] Kurata, 1970; [9] Gurney, 1937; Sankoli and Kewalramani, 1962; [10] Bruce, 1986; [11] Bourdillon-Casanova, 1960 (from plankton); [12] Calado *et al*., 2003; [13] Gurney and Lebour, 1941 (from plankton); [14] Occasionally.

sure caused by the harvest of wild populations has urged the need to implement sustainable collection practices and regulations to develop proper culture technologies (Calado *et al*., 2003).

The objective of the present work is to present a list of decapod crustaceans currently traded in the marine aquarium industry, highlighting possible ecological impacts of their harvest from the wild, and the main bottlenecks impairing the commercial culture of these species. Possible management and conservation guidelines to preserve these highly priced marine resources are also suggested.

Materials and Methods

In order to evaluate the number of decapod species currently traded in the marine aquarium industry, monthly surveys were conducted year round during 2002. Information was gathered from eight Portuguese aquarium retail stores, seven virtual pet stores on the World Wide Web (one Portuguese, one German, one British, and four North American), and two marine aquarium hobby magazines (Tropical Fish Hobbyist and Marine and Freshwater Aquarium). This preliminary list was complemented with the marine ornamental decapod species listed in Debelius (1984), Baensch and Debelius (1994), Fosså and Nielsen (2000), Dakin (2001), Fenner (2001), and Sprung (2001). In addition, several decapod species from European warm temperate and subtropical waters were included, because recent studies have revealed the potential use of such species in the marine aquarium trade.

The average unitary retail value of the most heavily traded ornamental decapods was estimated based on the prices presented by virtual pet stores on the World Wide Web.

Species were grouped according to the classification proposed by Martin and Davis (2001).

Results

The most heavily traded marine tropical decapods, as well as potential ornamental species from European warm temperate and subtropical waters, are listed in Tables 1–4.

Caridean shrimp species (49) clearly outnumber other decapod groups, with the Hippolytidae family alone accounting for 15 species. Anomuran and brachyuran crabs are the next two most traded groups, with 32 and 27 species respectively. Diogenid hermits clearly are the most popular anomuran species (20 species). The pricey Stenopodidean shrimp, Astacidea, and Palinura lobsters are represented by a considerably lower number of species (7, 7, and 6 species, respectively) (Fig. 1).

For the majority of species, larval development is either unknown or partially described (Tables 1–4). Even for the best-studied group, the brachyuran crabs (particularly majids), information on larval development only exists for a reduced number of species (Table 4).

Several ornamental decapod groups, especially caridean shrimp, display associative behaviour, either with invertebrate or vertebrate organisms (Tables 1–4). Certain caridean and stenopodidean shrimp are believed to be fish

Table 2. Distribution, culture profitability, commercial culture techniques, larval development, and associative behaviour of the most popular marine ornamental stenopodidean shrimp and lobsters in the aquarium trade industry. Abbreviations as in Table 1.

Scientific name	Distribution	CP	CCT	LD	AB
Stenopodidae					
Stenopus cyanoscelis	Western Pacific	HP	NA	U	–
Stenopus hispidus	Circumtropical	HP	BD	PK[2]	FC
Stenopus pyrsonotus	Indo-Pacific	HP	NA	U	FC
Stenopus scutellatus	Western Atlantic	HP	E[1]	PK[3]	FC
*Stenopus spinosus**	Eastern Atlantic	HP	BD	PK[4]	–
Stenopus tenuirostris	Indo-Pacific	HP	BD	U	–
Stenopus zanzibaricus	Indo-Pacific	HP	NA	U	–
Enoplometopodidae					
*Enoplometopus antillensis**	Atlantic	HP	BD	U	–
*Enoplometopus callistus**	Eastern Atlantic	HP	NA	U	–
Enoplometopus daumi	Indo-West Pacific	HP	NA	U	–
Enoplometopus debelius	Western Pacific	HP	NA	U	–
Enoplometopus holthuisi	Indo-Pacific	HP	NA	U	–
Enoplometopus occidentalis	Indo-Pacific	HP	NA	U	–
Enoplometopus voigtmanni	Indo-West Pacific	HP	NA	U	–
Palinuridae					
Justitia longimanus	Circumtropical	HP	NA	PK[5]	–
Panulirus versicolor	Indo-West Pacific	HP	NA	PK[8]	–
Panulirus guttatus	Western Atlantic	HP	NA	PK[7]	–
Synaxidae					
Palinurellus gundlachi	Western Atlantic	HP	NA	PK[6]	–
Palinurellus wieneckii	Indo-West Pacific	HP	NA	U	–
Scyllaridae					
Arctides regalis	Indo-Pacific	HP	NA	PK[9]	–

* Marine ornamental decapod species occurring in European warm temperate and subtropical waters. [1] Zhang *et al.*, 1998b; [2] Gurney and Lebour, 1941 (from plankton); [3] Gurney, 1936; [4] Seridji, 1990; [5] Robertson, 1969 (from plankton); Johnson and Robertson, 1970 (from plankton); [6] Sims, 1966 (from plankton); [7] Baisre and Alfonso, 1994 (from plankton); Briones-Fourzán and McWilliam, 1997 (from plankton); Lyons and Hunt, 1997 (from plankton); [8] Johnson, 1971 (from plankton); Michel, 1971 (from plankton); [9] Coutures, 2001.

Table 3. Distribution, culture profitability, commercial culture techniques, larval development, and associative behaviour of the most popular marine ornamental squat lobsters and anomuran crabs in the aquarium trade industry. Abbreviations as in Table 1.

Scientific name	Distribution	CCT	LD	AB
Galatheidae				
Allogalathea elegans	Indo-West Pacific	NA	U	AI
Porcellanidae				
Neopetrolisthes alobatus	Indo-West Pacific	NA	U	AI
Neopetrolisthes maculatus	Indo-West Pacific	NA	U	AI
Neopetrolisthes ohshimai	Indo-West Pacific	NA	U	AI
Coenobitidae				
Coenobita clypeatus	Western Atlantic	NA	K[1]	–
Coenobita compressus	Eastern Pacific	NA	K[2]	–
Coenobita perlata	Central Indo-Pacific	NA	U	–
Coenobita variabilis	Indo-Pacific	NA	U	–
Diogenidae				
Aniculus aniculus	Western Pacific	NA	U	–
Aniculus maximus	Indo-Pacific	NA	U	–
Calcinus californiensis	Eastern-Pacific	NA	U	–
Calcinus elegans	Indo-Pacific	NA	U	–
Calcinus laevimanus	Western Pacific	NA	U	–
Calcinus tibicen	Western Atlantic	NA	K[3]	–
*Calcinus tubularis**	Eastern Atlantic	NA	K[4]	–
Ciliopagurus striatus	Indo-Pacific	NA	U	–
*Clibanarius aequabilis**	Eastern Atlantic	NA	U	–
*Clibanarius erythropus**	Eastern Atlantic	NA	K[5]	–
Clibanarius tricolor	Western Atlantic	NA	U	–
Clibanarius virescens	Indo-West Pacific	NA	U	AI
Dardanus deformis	Indo-Pacific	NA	U	–
Dardanus guttatus	Indo-Pacific	NA	U	–
Dardanus lagopodes	Indo-West Pacific	NA	U	–
Dardanus megistos	Indo-West Pacific	NA	U	AI
Dardanus pedunculatus	Indo-West Pacific	NA	U	–
Paguristes cadenati	Western Atlantic	NA	U	–
*Paguristes eremita**	Eastern Atlantic	NA	K[4]	–
Petrochirus diogenes	Western Atlantic	NA	K[6]	–
Paguridae				
Manucomplanus varians	Pacific	NA	U	AI
Paguritta gracilipes	Pacific	NA	U	AI
*Pagurus prideaux**	Eastern Atlantic	NA	K[7]	AI
Phimochirus operculatus	Western Atlantic	NA	U	–

* Marine ornamental decapod species occurring in European warm temperate and subtropical waters. [1] Provenzano, 1962a; [2] Brodie and Harvey, 2001; [3] Provenzano, 1962b; [4] Pike and Williamson, 1960; [5] Le Roux, 1996; [6] Provenzano, 1968; [7] Goldstein and Bookhout, 1972.

cleaners (e.g., *Lysmata amboinensis*, *L. debelius*, *L. grabhami*, and *Stenopus hispidus*), whereas *Alpheus* and *Periclimenes* are known to live in close association with fish and invertebrates, respectively.

Suitable commercial culture techniques for marine ornamental decapods are still far from being established. Caridean and stenopodidean shrimp species have the highest number of established culture methodologies for traded species (10% and 14%, respectively) or for which culture methodologies are now being developed (43% and 12%, respectively). No study has addressed the culture of ornamental palinurid lobsters or anomuran crabs at a commercial level (Fig. 2).

Though some brachyuran and anomuran crabs also attain high market values (e.g., *Lybia tessalata* (Latreille, 1812), *Percnon gibbesi* (H. Milne Edwards, 1853), and *Manucomplanus varians* (Benedict, 1892)), lobsters and caridean and stenopodidean shrimp are the groups commanding the highest market prices (Table 5). The high prices of certain paired specimens (e.g., *Hymenocera* and *Stenopus*) is a consequence of their agonistic responses towards conspecifics of the same sex.

Discussion

Important bottlenecks impairing ornamental decapod culture (namely larviculture and broodstock maintenance) have been partially overcome in recent years (Calado *et al*., 2003). However, research efforts are still being focused on a very small number of traded species of the genus *Lysmata*, *Stenopus*, and *Hymenocera*.

Table 4. Distribution, culture profitability, commercial culture techniques, larval development, and associative behaviour of the most popular marine ornamental brachyuran crabs in the aquarium trade industry. Abbreviations as in Table 1.

Scientific name	Distribution	CCT	LD	AB
Dromiidae				
Cryptodromiopsis antillensis	Western Atlantic	E[1]	K[2]	AI
*Dromia marmorea**	Eastern Atlantic	NA	U	AI
*Dromia personata**	Eastern Atlantic	NA	K[3]	AI
Inachidae				
Camposcia retusa	Indo-Pacific	NA	U	–
*Inachus phalangium**	Eastern Atlantic	NA	K[4]	AI
*Inachus dorsettensis**	Eastern Atlantic	NA	K[5]	–
*Macropodia rostrata**	Eastern Atlantic	NA	K[6]	–
Stenorhynchus debilis	Eastern Pacific	NA	U	–
*Stenorhynchus lanceolatus**	Eastern Atlantic	NA	K[7]	AI[13]
Stenorhynchus seticornis	Western Atlantic	NA	K[8]	AI[13]
Mithracidae				
Leptopisa setirostris	Western Atlantic	NA	U	AI
Mithraculus forceps	Western Atlantic	BD	K[11]	–
Mithraculus sculptus	Western Atlantic	E[1]	U	–
Pisidae				
*Lissa chiragra**	Eastern Atlantic	NA	PK[9]	–
*Pisa armata**	Eastern Atlantic	NA	K[10]	–
Pelia mutica	Western Atlantic	NA	U	AI
Plagusiidae				
*Percnon gibbesi**	Atlantic	BD	K[12]	–
Portuniidae				
Lissocarcinus laevis	Indo-Pacific	NA	U	AI
Lissocarcinus orbicularis	Indo-Pacific	NA	U	–
Pseudoziidae				
*Euryozius bouvieri**	Eastern Atlantic	NA	U	–
Trapeziidae				
Trapezia ferruginea	Indo-Pacific	NA	U	AI
Trapezia rufopunctata	Indo-Pacific	NA	U	AI
Trapezia wardi	Indo-Pacific	NA	U	AI
Xanthidae				
Liomera cinctimana	Indo-Pacific	NA	U	–
Lybia edmonsoni	Pacific	NA	U	AI
Lybia tessalata	Indo-West Pacific	NA	U	AI
*Platypodiella picta**	Eastern Atlantic	NA	U	–

* Marine ornamental decapod species occurring in European warm temperate and subtropical waters. [1] Calado *et al*., 2003; [2] Rice and Provenzano, 1966; [3] *Rice et al*., 1970; [4]Lebour, 1928; [5] Ingle 1991; [6] Ingle, 1982; [7] Paula and Cartaxa, 1991; [8] Yang, 1976; [9] Bourdillon-Casanova 1960; [10] Rodríguez, 1997; [11] Wilson *et al*., 1979; [12] Paula and Hartnoll, 1989 (partially from plankton); [13] Ocasionally.

Long larval duration and/or low survival rates still impair the commercial rearing of most highly priced ornamental lobsters, caridean and stenopodidean shrimp. Knowledge of complete larval development in decapods is of vital importance for the evaluation of their rearing potential (Provenzano, 1985). Nevertheless, the complete larval development of the majority of traded species is still unknown or known from plankton samples. If some decapod families display a rather similar number of larval stages (e.g., porcelain and spider crabs), others such as alpheids present a wide range of larval stages, even within the same genus. Although detailed descriptions of alpheid larvae are still missing or incomplete (Yang and Kim, 1999), it is known that variable types of larval development occur: extended, abbreviated, and direct development (Knowlton, 1973). Besides the importance for culture purposes, the knowledge of ornamental species' early life history is also of extreme value for researchers working on the phylogenetic relationships of problematic decapod groups (Williamson and Rice, 1996).

Certain traded species have the remarkable ability to delay their larval development, considerably extending their larval period (see Gurney and Lebour, 1941). Scyllarid and palinurid lobsters are the classical examples of decapods with prolonged larval life, a remarkable strategy for larval dispersal (Williamson, 1967). Because of the research efforts on spiny lobster culture for human consumption (Kittaka, 1997a), the development of suitable commercial culture methodologies for the most popular spiny lobsters in the marine aquarium trade (*Justitia* spp. and some *Panulirus* spp.) may soon be achieved. Additionally, the close

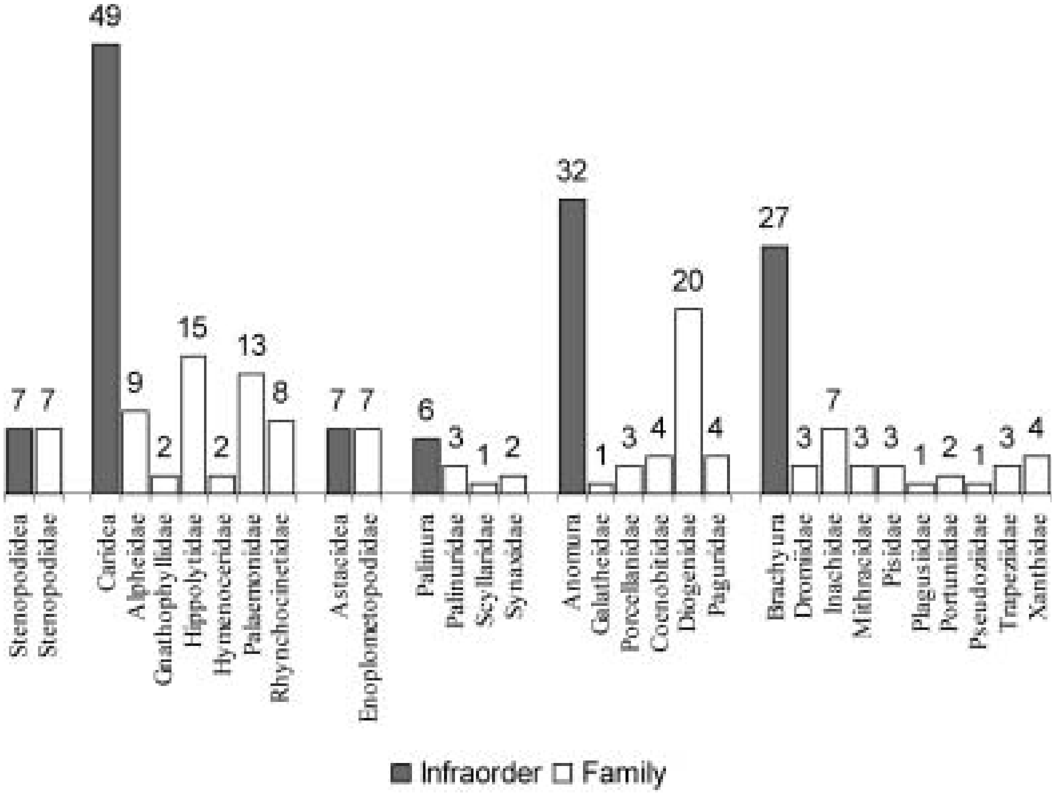

Fig. 1. Number of marine decapod crustacean species, per infraorder and family, traded in the marine aquarium industry (including decapod crustacean species occurring in European warm temperate and subtropical waters).

similarity of these larvae (Baisre, 1994) may allow culture improvements to be used for both groups. Calado *et al.* (2001) recorded the ability of *Lysmata seticaudata* (Risso, 1816) to delay larval development at certain larval stages through "mark-time molting" (as defined by Gore, 1985). Fletcher *et al.* (1995) also noticed the ability of certain decapods to delay larval development after recording 210 days of larval duration for *Stenopus hispidus* (Olivier, 1811). However, Zhang *et al.* (1997) raised the larvae of the sympatric species *Stenopus scutellatus* Rankin, 1898, in only 43 days, highlighting once more the plasticity of certain larval groups during their development.

A wide range of decapod crustaceans, particularly caridean shrimp, are known to be symbiotic with several invertebrate and fish species (Bruce, 1975). An important aspect that may condition the culture success of decapod species living in close association with invertebrates is the role of chemical cues released by the host organism in their larval development. Goy (1990) recorded the influence of chemical cues released by the host sea anemones of *Periclimenes pedersoni* Chace, 1958, and *P. yucatanicus* (Ives, 1891) in the settlement of late stage larvae and stressed the importance of such cues in the settlement of obligatory commensal decapods. The culture profitability of certain ornamental decapods can only be truly evaluated when their symbiotic relationships are understood (e.g., association between *Trapezia* spp. and hard corals; establishment of the association between boxer crabs, *Lybia* spp., and sea anemones of the genus *Bunodeopsis*). The culture of other obligatory commensal decapods (e.g., *Allopontonia* spp., *Stegopontonia* spp., and *Tuleariocaris* spp.) will be possible only if their hosts can be properly kept in captivity. Another widely known association from tropical and subtropical waters is that of alpheid shrimp and gobiid fish (Karplus *et al.*, 1972). Yanagisawa (1984) suggested that the shrimp/goby association is an obligate one and should occur soon after settlement. The importance of such associative behaviour in aquaculture has never been addressed.

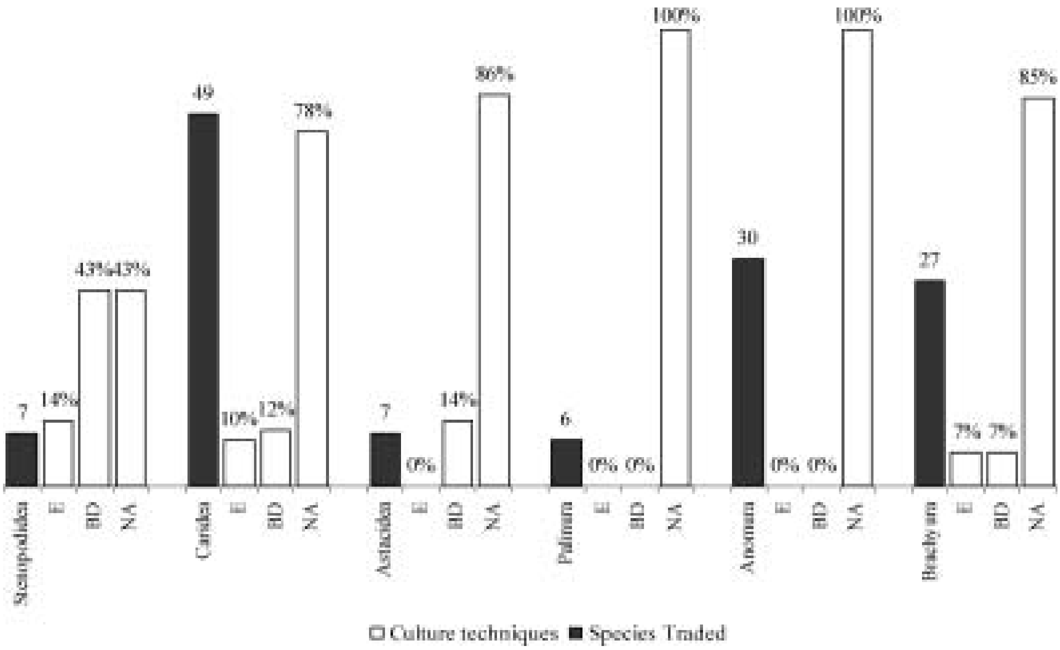

Fig. 2. Number of traded ornamental stenopodidean, caridean, astacidian, palinurid, anomuran, and brachyuran decapod crustaceans (including decapod crustacean species occurring in European warm temperate and subtropical waters) and status of the commercial culture techniques (%) (established, E; being developed, BD; not addressed, NA).

Rearing systems used to culture frail palinurid and scyllarid larvae (Illingworth *et al.*, 1997; Kittaka, 1997b; Ritar, 2001) appear to be suitable for the culture of other decapod larvae. The system developed by Calado *et al.* (2003), inspired by Greve's (1968) "planktonkreisel" and other larval spiny lobster culture systems, has proven to be suitable to raise caridean, stenopodidean, brachyuran, anomuran, and lobster larvae. In addition, this system allows larvae to be fed with nutritional prey (while assuring good water quality), to test settlement cues (by placing adult specimens or host organisms in the system head-tank), and to provide suitable settlement surfaces for late-stage larvae.

In the case of the expensive harlequin shrimp *Hymenocera picta* Dana, 1852, and *H. elegans* Heller, 1861, the main bottleneck impairing the culture of these species is the diet of juvenile and adult specimens, because they feed exclusively on sea stars.

Although hermit crabs are extremely popular in the aquarium hobby, the culture of these organisms will happen only if the capture of wild specimens is restricted. Several authors have stressed the factors conditioning the settlement of hermit crab megalopa (Harms, 1992; Harvey, 1996). The main limitation for the commercial culture of these species is not their larval stages but the demand for a constant supply of specific and suitably sized shells (Worcester and Gaines, 1997), one of the factors conditioning settlement and growth rates of hermit crabs (Bertness, 1981; Blackstone, 1985). This tedious and time-consuming need of a constant shell supply would likely cause cultured hermits to be much more expensive than captured specimens.

The culture of ornamental brachyuran crabs (particularly the genus *Mithraculus* White, 1847) and anomuran porcelain crabs (particularly the genus *Neopetrolisthes* Miyake, 1937) is not as complex as the culture of popular lobsters and shrimp. The reduced number of larval stages (two zoeal stages and a megalopa, see Anger, 2001), and consequent short larval stage duration, should be an appealing aspect for the commercial culture of these organisms. Although the commercial culture of the Caribbean king crab *Mithrax spinosissimus* (Lamarck, 1818) has been already attempted in the laboratory (Tunberg and Creswell, 1988), no study has ever addressed the possibility of using similar methodologies to raise its ornamental relatives *Mithraculus sculptus* (Lamarck, 1818) and *M. forceps* A. Milne-Edwards, 1875.

Table 5. Average commercial value (U.S. dollars per specimen) of some popular and highly priced marine ornamental decapod crustaceans.

Scientific name	Common name	Average commercial value (U.S. dollars)
Alpheus ochrostriatus	Fine-stripped snapping shrimp	15
Lysmata amboinensis	Skunk cleaner shrimp	20
Lysmata debelius	Fire shrimp	25
Lysmata wurdemanni	Peppermint shrimp	8
Saron marmoratus	Marble shrimp	15
Hymenocera picta	Harlequin shrimp	30 (80)[#]
Periclimenes pedersoni	Pederson's commensal shrimp	10
Rhynchocinetes durbanensis	Camel shrimp	6
Stenopus hispidus	Barber pole boxing shrimp	15 (40)[#]
Stenopus scutellatus	Golden boxer shrimp	20 (50)[#]
Enoplometopus debelius	Debelius's dwarf reef lobster	25
Enoplometopus occidentalis	Red dwarf reef lobster	30
Panulirus versicolor	Painted spiny lobster	35
Neopetrolisthes maculatus	Porcelain crab	7
Clibanarius tricolor	Blue legged hermit crab	1.5
Paguristes cadenati	Red legged hermit crab	3
Manucomplanus varians	Staghorn hermit crab	30
Stenorhynchus seticornis	Arrow crab	10
Mithraculus sculptus	Emerald crab	8
Percnon gibbesi	Sally lightfood	15
Lybia tessalata	Boxer crab	30

[#] Price per pair.

The main reason for the existence of such "research bias" towards ornamental shrimp and lobsters must be the low unitary value that most brachyuran and anomuran crabs command in the aquarium trade. A recent survey among marine ornamental commercial breeders in the U.S. revealed that *Lysmata* spp., *Stenopus* spp., *Enoplometopus* spp., and *Hymenocera* spp. were considered as "the most desirable crustacean species to be reared" (Martin A. Moe, Jr., personal communication). In addition, certain hermit crabs (e.g., *Clibanarius tricolor* (Gibbes, 1850)) and majid crabs (e.g., *Mithraculus sculptus*), popular in the hobby as members of "algae cleaning crews," can readily be harvested in considerable numbers, either by traders or hobbyists, in intertidal regions or shallow water accessible with snorkeling gear.

The ecological impacts associated with ornamental shrimp capture are still largely unknown. Some collection of ornamental decapods may have considerable impacts due to the large number of specimens captured and/or the special roles these species play in the natural ecosystem. Although Spotte (1998) questions the existence of cleaner shrimp, the ecological importance of cleaning symbiosis has long been claimed (see Losey, 1972; Jonasson, 1987; Côté, 2000) and has recently been experimentally confirmed for the genus *Periclimenes* O.G. Costa, 1844 (Kulbicki and Arnal, 1999). The collection of large numbers of *Lysmata* spp., *Stenopus* spp., and *Periclimenes* spp. for display and fish cleaning may affect the health condition of several reef fish species. Another example of potential collection impact on reefs may be the capture of large numbers of harlequin shrimp, *Hymenocera* spp., because these shrimp are known to prey on the crown-of-thorns sea star, a known predator of corals (Talbot and Talbot, 1971).

Though cyanide use for ornamental fish collection is now a widespread practice in the major marine ornamental exporting countries in Southeast Asia (Jones and Steven, 1997), the physiological effects of this asphyxiant in decapod crustaceans and other invertebrate organisms in coral reefs are still unknown.

Although some countries have already implemented regulations of marine ornamental collection (e.g., Larkin *et al.*, 2001), decapod crustaceans are sometimes overlooked. Though common sense indicates that collection of wild decapod specimens must be reduced, the fact is that important studies on target species' biology are missing. In order to establish appropriate measures for the management of marine ornamental decapod capture, such as operating by species-based quotas or issuing a limited number of collection permits, information on target species' reproductive biology, growth, population structure, and recruitment must be analysed (see Bolker *et al.*, 2002). Nevertheless, reducing or banning the collection of decapod species, for which commercial culture protocols have been established, could certainly help minimise the impact of wild specimens harvest. Although

European countries have no specific legislation on autochthonous ornamental decapod collection, the knowledge of the life-history aspects of several potential ornamental crustaceans from warm temperate and subtropical European waters can help on future legislation.

The only suitable way to achieve a sustainable management of the collection of marine ornamental decapods, while continuing to solve the bottlenecks impairing these species' culture, is to promote a multidisciplinary cooperation between researchers working on larval biology, population dynamics, ecology, aquaculture, and fisheries.

Acknowledgements

The authors thank Fundação para a Ciência e a Tecnologia (scholarship SFRH/BD/983/2000 and research project POCTI/BSE/43340/2001) from the Portuguese government for the financial support. We thank Joana Figueiredo and Lueji Pestana for their comments on the manuscript. We express our sincere gratitude to Paul F. Clark from The Natural History Museum, London, and two anonymous referees for their valuable comments on the manuscript. We thank Martin A. Moe, Jr., of Green Turtle Publications, for making available to us his report "Culture of Marine Ornamentals: For Love, for Money, and for Science" during the Marine Ornamentals 2001 Meeting.

Literature Cited

Al-Kholy, A. A. 1960. Larvae of some macruran Crustacea (from the Red Sea).—Publications of the Marine Biology Station of Al Ghardaqa 11: 73–85.

Anger, K. 2001. The biology of decapod crustacean larvae. Pp. 1–419 *in* R. Vonk, ed. The Biology of Decapod Crustacean Larvae. Crustacean Issues. Vol. 14. A. A. Balkema Publishers, Rotterdam, Netherlands.

Baensch, H., and H. Debelius. 1994. Marine Atlas. Vol. 1. Ed. Mergus, Germany. 1215 pp.

Baisre, J. 1994. Phyllosoma larvae and phylogeny of Palinuroidea (Crustacea: Decapoda): a review.—Australian Journal of Marine and Freshwater Research 45: 925–944.

———, and I. Alfonso. 1994. Later stage larvae of *Panulirus guttatus* (Latreille, 1804) (Decapoda, Palinuridae) with notes on the identification of phyllosomata of *Panulirus* in the Caribbean Sea.—Crustaceana 66: 32–44.

Bertness, M. D. 1981. The influence of shell type on hermit crab growth rate and clutch size (Decapoda, Anomura).—Crustaceana 40: 197–205.

Blackstone, N. W. 1985. The effects of shell size and shape on growth and form in the hermit crab *Pagurus longicarpus*.—Biological Bulletin 168: 75–90.

Bolker, B. M., C. M. St. Mary, C. W. Osenberg, R. J. Schmitt, and S. J. Holbrook. 2002. Management at a different scale: marine ornamentals and local processes.—Bulletin of Marine Science 70: 733–748.

Bourdillon-Casanova, L. 1960. Le meroplancton du Golfe de Marseille: les larves des crustacés decapodes.—Recueil Des Travaux De La Station Marine D'Endoume 30: 1–286.

Briones-Fourzán, P., and P. S. McWilliam. 1997. Puerulus of the spiny lobster *Panulirus guttatus* (Latreille, 1804) (Palinuridae).—Marine and Freshwater Research 48: 699–705.

Brodie, R., and A. W. Harvey. 2001. The complete larval development of *Coenobita compressus* (Crustacea: Decapoda: Coenobitidae), reared in the laboratory.—Journal of Crustacean Biology 21: 715–732.

Bruce, A. J. 1975. Les crevettes des récifs coralliens et leurs colleurs.—Endeavour 24: 23–27.

———. 1986. Observations on the family Gnathophyllidae Dana, 1852 (Crustacea: Decapoda).—Journal of Crustacean Biology 6: 463–470.

Bruckner, A. W. 2001. Tracking the trade in ornamental coral reef organisms: the importance of CITES and its limitations.—Aquarium Sciences and Conservation 3: 79–94.

Calado, R., C. Martins, O. Santos, and L. Narciso. 2001. Larval development of the Mediterranean cleaner shrimp *Lysmata seticaudata* (Risso, 1816) (Caridea; Hippolytidae) fed on different diets: costs and benefits of mark-time molting.—Larvi'01 Fish and Crustacean Larviculture Symposium, European Aquaculture Society, Special Publication 30: 96–99.

———, L. Narciso, S. Morais, A. L. Rhyne, and J. Lin. 2003. A rearing system for the culture of ornamental decapod crustacean larvae.—Aquaculture 218: 329–339.

Caroli, E. 1918. *Miersia clavigera* Chun, stadio misidiforme di *Lysmata seticaudata* Risso.—Pubblicazione De La Stazione Zoologica Di Napoli II: 177–189.

Côté, I. M. 2000. Evolution and ecology of cleaning symbioses in the sea.—Oceanography and Marine Biology: An Annual Review 38: 311–355.

Coutures, E. 2001. On the first phyllosoma stage of *Parribacus caledonicus* Holthuis, 1960, *Scyllarides squamosus* (H. Milne-Edwards, 1837) and *Arctides regalis* Holthuis, 1963 (Crustacea, Decapoda, Scyllaridae) from New Caledonia.—Journal of Plankton Research 23: 745–751.

Dakin, N. 2001. The Marine Aquarium Problem Solver. Tetra Press, Virginia. 208 pp.

Debelius, H. 1984. Armoured Knights of the Sea. Quality Marine, Los Angeles. 120 pp.

Fenner, R. M. 2001. The Conscientious Marine Aquarium. TFH Publication, New Jersey. 430 pp.

Fiedler, G. C. 1994. The larval stages of the harlequin shrimp, *Hymenocera picta* (Dana).—M.S. Thesis, University of Hawaii at Manoa, U.S.A. 101 pp.

Fletcher, D., I. Kotter, M. Wunsch, and I. Yasir. 1995. Preliminary observations on the reproductive biology of ornamental cleaner prawns.—International Zoo Yearbook 34: 73–77.

Fosså, S. A., and A. J. Nielsen. 2000. The Modern Coral Reef Aquarium. Vol. 3. Birgit Schmettkamp Verlag, Bornheim. 448 pp.

Goldstein, B., and C. G. Bookhout. 1972. The larval development of *Pagurus prideauxi* Leach, 1814, under laboratory conditions (Decapoda Paguridea).—Crustaceana 23: 263–281.

Gore, R., 1985. Molting and growth in decapod larvae. Pp. 1–65 *in* A. M. Wenner, ed. Larval Growth. Crustacean Issues. Vol. 2. A. A. Balkema Publishers, Rotterdam, Netherlands.

Goy, J. W. 1990. Components of reproductive effort and delay of larval metamorphosis in tropical marine shrimp (Crustacea: Decapoda: Caridea and Stenopodidea).—Ph.D. Dissertation, University of Texas, Texas, U.S.A. 177 pp.

Greve, W. 1968. The "planktonkreisel", a new device for culturing zooplankton.—Marine Biology 1: 201–203.

Gurney, R. 1936. Larvae of decapod Crustacea. Part I. Stenopidae. Part II. Amphionidae. Part III. Phyllosoma.—Discovery Reports 12: 377–440.

———. 1937. Larvae of decapod Crustacea. Part IV. Hippolytidae.—Discovery Reports 14: 351–404.

———, and M. V. Lebour. 1941. On the larvae of certain Crustacea Macrura, mainly from Bermuda.—Journal of the Linnean Society of London (Zoology) 41: 89–181.

Harms, J. 1992. Larval development and delayed metamorphosis in the hermit crab *Clibanarius erythropus* (Latreille) (Crustacea, Diogenidae).—Journal of Experimental Marine Biology and Ecology 156: 151–160.

Harvey, A. W. 1996. Delayed metamorphosis in Florida hermit crabs: multiple cues and constraints (Crustacea: Decapoda: Paguridae and Diogenidae).—Marine Ecology: Progress Series 141: 27–36.

Illingworth, J., L. Tong, G. Moss, and T. Pickering. 1997. Upwelling tank for culturing rock lobster (*Jasus edwardsii*) phyllosomas.—Marine and Freshwater Research 48: 911–914.

Ingle, R. W. 1982. Larval and post-larval development of the slender legged spider crab, *Macropodia rostrata* (Linnaeus) (Oxyrhyncha: Majidae: Inachinae), reared in the laboratory.—Bulletin of the British Museum of Natural History (Zoology) 42: 207–225.

———. 1991. Larval Stages of Northeastern Atlantic Crabs. An Illustrated Key. Chapman and Hall, London. 363 pp.

Johnson, M. W. 1971. On palinurid and scyllarid lobster larvae and their distribution in the South China Sea (Decapoda, Palinuridae).—Crustaceana 21: 247–282.

———, and P. B. Robertson. 1970. On the phyllosoma larvae of the genus *Justitia* (Decapoda, Palinuridae).—Crustaceana 18: 283–292.

Jonasson, M. 1987. Fish cleaning behaviour of shrimp.—Journal of Zoology, London 213: 117–131.

Jones, R. J., and A. L. Steven. 1997. Effect of cyanide in relation to cyanide fishing on reefs.—Marine and Freshwater Research 48: 517–522.

Karplus, I., R. Szlep, and M. Tsurnamal. 1972. Associative behaviour of the fish *Cryptocentrus cryptocentrus* (Gobiidae) and the pistol shrimp *Alpheus djiboutensis* (Alpheidae) in artificial burrows.—Marine Biology 15: 95–104.

Kittaka, J. 1997a. Culture of larval spiny lobsters: a review of work done in northern Japan.—Marine and Freshwater Research 48: 923–930.

———. 1997b. Application of ecosystem method for complete development of phyllosomas of spiny lobster.—Aquaculture 155: 319–331.

Knowlton, R. E. 1973. Larval development of the snapping shrimp *Alpheus heterochelis* Say, reared in the laboratory. —Journal of Natural History 7: 273–306.

Kulbicki, M., and C. Arnal. 1999. Cleaning of fish ectoparasites by a Palaemonidae shrimp on soft bottoms in New Caledonia.—Cybium 23: 101–104.

Kurata, H. 1970. Studies on the life histories of decapod Crustacea of Georgia.—Ph.D. Dissertation, University of Georgia, Sapelo Island, Georgia, U.S.A. 274 pp.

Larkin, S. L., C. M. Adams, R. L. Degner, D. J. Lee, and J. W. Milon. 2001. An economic profile of Florida's marine life industry.—Florida Sea Grant Technical Paper 113: 1–63.

Le Roux, A. 1966. Contribution a l'étude du développement larvaire de *Clibanarius erythropus* (Latreille) (Crustacé Decapode Anomure Diogénidé).—Cahiers De Biologie Marine 7: 225–230.

Lebour, M. V. 1928. The larval stages of the Plymouth Brachyura. Proceedings of the Zoological Society of London 473–560.

———. 1932. The larval stages of the Plymouth Caridea. IV. The Alpheidae.—Proceedings of the Zoological Society of London 463–469.

Lin, J. 2000. Errata.—Journal of the World Aquaculture Society 31: 476.

Losey, G., Jr. 1972. The ecological importance of cleaning symbiosis.—Copeia 4:820–833.

Lukhaup, C. 2002. Shells & pincers.—Tropical Fish Hobbyist 51: 90–94.

Lyons, W. G., and J. H. Hunt. 1997. The puerulus of the spotted spiny lobster, *Panulirus guttatus* (Latreille 1804) (Crustacea: Decapoda).—Marine and Freshwater Research 48: 491–495.

Martin, J. W., and G. E. Davis. 2001. An updated classification of the Recent Crustacea.—Natural History Museum of Los Angeles County, Science Series 39: 1–124.

Michel, A. 1971. Note sur les puerulus de Palinuridae et les larves phyllosomes de *Panulirus homarus* (L.). Clef de détermination des larves phyllosomes récoltêes dans le Pacifique équatorial et sud-tropical (décapodes).—Cahiers O.R.S.T.O.M, Série Océnagraphie 9: 459–473.

Paula, J., and A. Cartaxana. 1991. Complete larval development of the spider crab *Stenorhynchus lanceolatus* (Brullé, 1837) (Decapoda, Brachyura, Majidae), reared in the laboratory.—Crustaceana 60: 113–122.

———, and R. G. Hartnoll. 1989. The larval and post-larval development of *Percnon gibbesi* (Crustacea, Brachyura, Grapsidae) and the identity of the larval genus *Pluteocaris*.—Journal of Zoology, London 218: 17–37.

Pike, R., and D. I. Williamson. 1960. Larvae of decapod Crustacea of the families Diogenidae and Paguridae from the Bay of Naples.—Pubblicazione De La Stazione Zoologica Di Napoli 21: 493–552.

Provenzano, A. J., Jr. 1962a. The larval development of the tropical land hermit *Coenobita clypeatus* (Herbst) in the laboratory.—Crustaceana 4: 207–228.

———. 1962b. The larval development of *Calcinus tibicen* (Herbst) (Crustacea, Anomura) in the laboratory.—Biological Bulletin 123: 179–202.

———. 1968. The complete larval development of the West Indian hermit crab *Petrochirus diogenes* (L.) (Decapoda, Diogenidae) reared in the laboratory.—Bulletin of Marine Science 18: 143–181.

———. 1985. Commercial culture of decapod crustaceans. Pp. 269–314 *in* A. J. Provenzano, Jr. ed. Economic Aspects: Fisheries and Culture. The Biology of Crustacea. Vol. 10. Academic Press, New York.

Rice, L. A., and A. J. Provenzano, Jr. 1966. The larval development of the West Indian sponge crab *Dromidia antillensis* (Decapoda: Dromiidae).—Journal of Zoology, London 149: 297–319.

———, R. W. Ingle, and E. Allen. 1970. The larval development of the sponge crab *Dromia personata* (L.) (Crustacea, Decapoda, Brachyura) reared in the laboratory.—Vie et Milieu 21: 223–240.

Ritar, A. J. 2001. The experimental culture of phyllosoma larvae of southern rock lobster (*Jasus edwardsii*) in a flow-through system.—Aquacultural Engineering 24: 149–156.

Robertson, P. B. 1969. Phyllosoma larvae of a palinurid lobster, *Justitia longimana* (H. Milne Edwards), from the Western Atlantic.—Bulletin of Marine Science 19: 922–944.

Rodríguez, A. 1997. Larval and postlarval development of *Pisa tetraodon* (Pennant, 1777) (Decapoda, Majidea) reared in the laboratory.—Journal of Plankton Research 19: 29–41.

Sankolli, K., and H. G. Kewalramani. 1962. Larval development of *Saron marmoratus* (Olivier) in the laboratory.—Journal of the Marine Biological Association of India 4: 106–120.

Seridji, R. 1990. Description of some planktonic larval stages of *Stenopus spinosus* Risso, 1826: notes on the genus and systematic position of the Stenopodidea as revealed by larval characters.—Scientia Marina 54: 293–303.

Sims, H. W., Jr. 1966. The phyllosoma larvae of the spiny lobster *Palinurellus gundlachi* Von Martens (Decapoda, Palinuridae).—Crustaceana 11: 205–215.

Spotte, S. 1998. "Cleaner" shrimps?—Helgolander Meeresunters 52: 59–64.

Sprung, J. 2001. Oceanographic Series™ —Invertebrates, A Quick Reference Guide. Ricordea Publishing, Florida. 240 pp.

Talbot, F. H., and M. S. Talbot. 1971. L'étoile de mer "Couronne d'épines" (*Acanthaster*) et les récifs de la Grande Barrière.—Endeavour 30: 38–42.

Tlusty, M. 2002. The benefits and risks of aquacultural production for the aquarium trade.—Aquaculture 205: 203–219.

Tunberg, B. G., and R. L. Creswell. 1988. Early growth and mortality of the Caribbean king crab *Mithrax spinosissimus* reared in the laboratory.—Marine Biology 98: 337–343.

Williamson, D. I. 1967. Some recent advances and outstanding problems in the study of the larval Crustacea. —Proceedings of the Symposium on Crustacea–Part II: 815–823.

———, and A. Rice. 1996. Larval evolution in the Crustacea.—Crustaceana 69: 267–287.

Wilson, K. A, L. E. Scotto, and R. H. Gore. 1979. Studies on decapod Crustacea from the Indian River region of Florida. XIII. Larval development under laboratory conditions of the spider crab *Mithrax forceps* (A. Milne-Edwards, 1875) (Brachyura: Majidae).—Proceedings of the Biological Society of Washington 92: 307–327.

Wood, E. 2001. Global advances in conservation and mangement of marine ornamental resources.—Aquarium Sciences and Conservation 3: 65–77.

Worcester, S. E., and S. D. Gaines. 1997. Quantifying hermit crab recuitment rates and megalopal shell selection on a wave-swept shore.—Marine Ecology: Progress Series 157: 307–310.

Wunsch, M. 1996. Larval Development of *Lysmata amboinensis* (De Man, 1888) (Decapoda: Hippolytidae) reared in the laboratory with a note on *L. debelius* (Bruce, 1983).—M.S. Thesis, University of Wales, Bangor, U.K. 110 pp.

Yanagisawa, Y. 1984. Studies on the interspecific relationship between gobbid fish and snapping shrimp. II. Life history and pair formation of snapping shrimp *Alpheus bellulus*.—Publications of the Seto Marine Biological Laboratory 29: 93–116.

Yang, H. J., and C. H. Kim. 1999. The early zoeal stages of *Alpheus heeia* Banner & Banner, 1975 reared in the laboratory (Decapoda, Caridea, Alpheidae).—Crustaceana 72: 25–36.

Yang, W. T. 1976. Studies on the western Atlantic arrow crab genus *Stenorhynchus* (Decapoa, Brachyura, Majidae). I. Larval characters of two species and comparison with other larvae of Inachinae.—Crustaceana 31: 157–177.

Zhang, D., J. Lin, and R. L. Creswell. 1997. Larviculture and effect of food on larval survival and development in golden coral shrimp *Stenopus scutellatus*.—Journal of Shellfish Research 16: 367–369.

———, ———, and ———. 1998a. Effects of food and temperature on survival and development in the peppermint shrimp *Lysmata wurdemanni*.—Journal of the World Aquaculture Society 29: 471–476.

———, ———, and ———. 1998b. Mating behavior and spawning of the banded coral shrimp *Stenopus hispidus* in the laboratory.—Journal of Crustacean Biology 18: 511–518.

RECEIVED: 28 February 2003.
ACCEPTED: 30 April 2003.

ANNOUNCEMENT

The Crustacean Society recognized outstanding student oral and poster presentations given at the TCS mid-year meeting, which was held June 1–5 in Williamsburg, Virginia, and sponsored by the Virginia Institute of Marine Science, College of William & Mary. Each award winner receives a certificate, a free one-year membership in TCS (which includes a subscription to the *Journal of Crustacean Biology*), and a cash award of $50.00. The recipient for Best Student Oral Presentation was J. Antonio Baeza (University of Louisiana, Lafayette) for his talk entitled, "Experimental tests of socially mediated sex change in a simultaneous hermaphrodite, the shrimp *Lysmata wurdemanni* (Crustacea: Caridea)" (co-author: Raymond Bauer). The recipient for Best Student Poster was Russ Barbour (University of North Carolina, Wilmington) for his poster entitled, "Availability of brachyuran megalopae and settlement patterns of *Callinectes sapidus* megalopae in the Cape Fear River estuary, NC" (co-authors M. H. Posey and T. D. Alphin). We extend congratulations to these winners and thanks to the other student participants.