Lat. Am. J. Aquat. Res., 37(3): 543-554, 2009
"Deep-sea fisheries off Latin America"
P. Arana, J.A.A. Perez & P.R. Pezzuto (eds.)
DOI: 10.3856/vol37-issue3-fulltext-19

Review

The deepwater fishery along the Pacific coast of Costa Rica, Central America

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ABSTRACT. Global catches of marine fishery resources declined during the last decades; however, there has been a trend of increasing exploitation of deepwater resources that are especially vulnerable to depletion. Such a tendency was noticeable in Pacific Latin America, too. In Costa Rica, the vast majority of the commercial fishing activities are concentrated on the Pacific coast. The target species for the deepwater fishery in Costa Rica are the two pandalids *Heterocarpus affinis* and *H. vicarius* as well as *Solenocera agassizii*, the latter one being the most important in terms of annual landings. Here we compile the information available from Costa Rica about each of the three target species. Furthermore, we describe research activities related to the Costa Rican deepwater resources and present available data about by-catch and discards in this fishery. Finally, the current situation of the administration and management of these resources in Costa Rica is described. Strengthening collaboration between governmental agencies, the fishery sector, non-governmental organizations, and the academic sector is recommended to avoid an uncontrolled overfishing of these valuable deepwater resources along the Pacific coast of Costa Rica.

Keywords: shrimp, Pandalidae, Solenoceridae, *Heterocarpus*, *Solenocera agassizii*, fishery management, by-catch, discard, Costa Rica.

Pesca en aguas profundas a lo largo de la costa Pacífica de Costa Rica, América Central

RESUMEN. Las capturas globales de los recursos marinos pesqueros disminuyeron durante las últimas décadas. Sin embargo, se ha observado una tendencia de aumento en la explotación de los recursos de aguas profundas, los cuales son especialmente vulnerables a la extracción. Esta tendencia ha sido notable también en la pesca a lo largo del Pacífico de Latino América. En Costa Rica, la mayoría de las actividades pesqueras comerciales se concentran en la costa del Pacífico. Las especies objetivo de la pesca de aguas profundas en Costa Rica son los dos pandálidos *Heterocarpus affinis* y *H. vicarius* así como *Solenocera agassizii*, siendo esta última la más importante respecto a las capturas anuales. Se compila la información disponible sobre las tres especies objetivo de Costa Rica. Además, se describen las actividades de investigación relacionadas con los recursos de aguas profundas en Costa Rica y se presentan los datos disponibles sobre la fauna acompañante y el descarte en esa pesquería. Finalmente, se describe la situación actual de la administración y manejo de dichos recursos en Costa Rica. Se recomienda fortalecer la colaboración entre las agencias gubernamentales, el sector pesquero, las organizaciones no-gubernamentales y el sector académico para evitar la sobre-explotación sin control de estos valiosos recursos de aguas profundas del Pacífico de Costa Rica.

Palabras clave: camarones, Pandalidae, Solenoceridae, *Heterocarpus*, *Solenocera agassizii*, manejo pesquero, fauna acompañante, descarte, Costa Rica.

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GENERAL BACKGROUND

The Food and Agriculture Organization (FAO) of the United Nations started compiling global fishery statistics in the 1950s. Their data indicated a rapid increase in catches during the 1950s and 1960s; in the mid-1980s a decline of the total catches became evident, and this trend accelerated between the late-1980s and early-1990s (Pauly *et al.*, 2002, 2005; Zeller & Pauly, 2005). Global catches seemed to increase during the 1990s; however, the study by Watson & Pauly (2001) revealed a systematic distortion in world fisheries catch trends, mainly due to a substantial over-reporting of catches from the People's Republic of China. The corrected data indicated, in fact, a declining trend since the late 1980s (Watson & Pauly, 2001; Pauly *et al.*, 2002; Schoijet, 2002). Moreover, this trend was also masked by an increasing exploitation of deepwater resources (Pauly *et al.*, 2005).

In general, fishing activities have concentrated on resources inhabiting shallow-water coastal areas. The decline of these resources together with the increasing demand and the development of new technologies resulted in an expansion of fisheries in offshore areas and deeper water (Pauly *et al.*, 2005; Morato *et al.*, 2006). In fact, the mean depth of bottom fish catches increased from around 103 m (early 1950s) to 145 m in 2001 (Morato *et al.*, 2006). According to these authors, the depth increase was especially pronounced after 1978, with a rate of 13 m decade^{-1}.

Deepwater species are considered to have a longer life span, later sexual maturity, lower fecundity, and slower growth; all these life history characteristics make them especially vulnerable to depletion with a low capacity for recovery from over-exploitation (Cheung *et al.*, 2005; Morato *et al.*, 2006). A major limitation for the development and implementation of management measures is the lack of life history data of the exploited deepwater species (Polidoro *et al.*, 2008).

The trend toward the exploitation of deepwater resources is also noticeable in Pacific Latin America. The depletion of shallow water resources together with fishing restrictions aimed at preserving the threatened populations have fostered increasing interest, on the part of the fishing industry and scientists, in identifying alternative resources in deepwater systems (Arana *et al.*, 2002; Wehrtmann & Echeverría-Sáenz, 2007). In recent years, several publications broadened our knowledge about the diversity (e.g., Retamal, 1993; Guzmán & Quiroga, 2005; MacPherson & Wehrtmann, in press), biology and ecology of deepwater decapods in Latin America (e.g., *Campylonotus semistriatus*: Arana & Ahumada, 2006; *Haliporoides diomedeae*: Arana *et al.*, 2003; *Neolithodes diomedeae* and *Paralomis otsuae*: Bahamonde & Leiva, 2003). Moreover, Hendrickx (2003) published the results of several studies concerning the deepwater decapod fauna of the Golfo de California, Mexico. All these studies focused on Chilean and Mexican waters, and virtually nothing is known about deepwater resources in Central America: Wehrtmann & Echeverría-Sáenz (2007) described the crustacean fauna associated with the fishery of the deepwater shrimp *Heterocarpus vicarius*, and MacPherson & Wehrtmann (in press) provided information on the occurrence of lithodid crabs off Pacific Costa Rica.

FISHERY IN COSTA RICA

Although Costa Rica can be considered to be a relatively small country (land mass: 51,100 km^2), its marine area, including Territorial Seas and Exclusive Economic Zones (EEZ), is considerable and roughly ten times larger than the land mass (589,683 km^2: INCOPESCA, 2006). This surprising fact can be attributed to the 200-mile zone in the Pacific, including offshore Isla del Coco, that greatly enlarges the Exclusive Economic Zone of Costa Rica (Quesada-Alpízar, 2006a). Due to this situation, the marine territory of Costa Rica shares borders with Ecuador and Colombia.

Starting around the 1990s, aquaculture began to contribute to the total shrimp production of Costa Rica. The importance of the aquaculture production increased steadily, although the fishery landings during the late 1990s and early 2000s still comprised the vast majority of the production of Costa Rica. This situation changed in recent years (2004-2007): the landing of the fishery sector decreased and, at the same time, aquaculture production increased considerably. Nowadays, the contribution of the aquaculture sector in Costa Rica is nearly of the same magnitude as that of the fishery landings (Fig. 1).

The vast majority of commercial fishing activities and landings are concentrated on the Pacific coast of Costa Rica (Fig. 2), which covers approximately 1254 km versus only 212 km on the Caribbean coast (Cortés & Wehrtmann, 2009). In the Pacific, the Golfo de Nicoya is the most important fishery ground in the country, accounting for roughly 30% of the annual landings (Vargas, 1995; Cortés & Wehrtmann, 2009). However, commercial bottom trawling is not allowed in the inner part of the gulf and, thus, the small-scale fishery is the prevailing type of fishing activity in the Golfo de Nicoya.

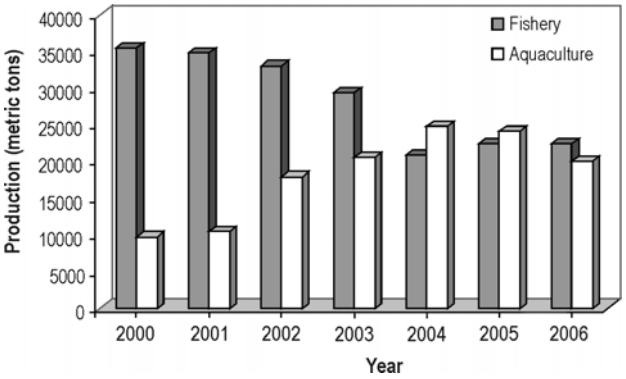

Figure 1. Fishery and aquaculture production in Costa Rica between the year 2000 and 2006 (data from FAO, 2009).

Figura 1. Producción en pesca y acuicultura en Costa Rica durante los años 2000 y 2006 (datos: FAO, 2009).

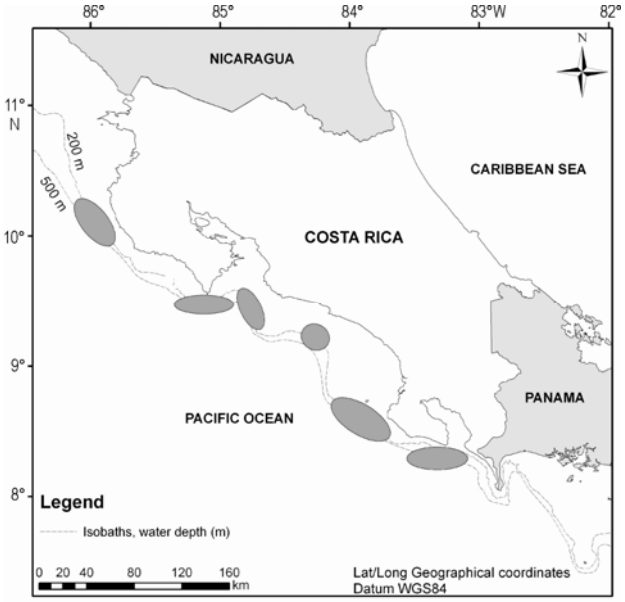

Figure 2. Main fishing grounds of the deepwater fishery (excluding *Heterocarpus affinis*) along the Pacific coast of Costa Rica.

Figura 2. Principales áreas de pesca en aguas profundas (excluyendo *Heterocarpus affinis*) a lo largo de la costa del Pacífico de Costa Rica.

The semi-industrial shrimp fishery in Costa Rica originated in the 1950s with the introduction of bottom trawl nets; the first shrimp fishery statistics date from 1952 and indicate landings of 43.2 tons (Tabash-Blanco, 2007, and references cited therein). In the beginning, the principal target species of coastal shrimp fisheries were *Penaeus* (*Litopenaeus*) *occidentalis* Streets, 1871 and *Penaeus (Litopenaeus) vannamei* Boone, 1931; other shrimp species were discarded (Tabash-Blanco, 2007). Currently, the following shrimp species are commercially exploited along Pacific Costa Rica: *Penaeus* (*Farfantepenaeus*) *californiensis* Holmes, 1900 ("camarón café"), *Penaeus* (*Farfantepenaeus*) *brevirostris* Kingsley, 1878 ("camarón pinki" or "camarón rosado"), *Penaeus* (*Litopenaeus*) *occidentalis* ("camarón blanco del Pacífico"), *Penaeus* (*Litopenaeus*) *stylirostris* Stimpson, 1874 ("camarón azul"), *Penaeus* (*Litopenaeus*) *vannamei* ("camarón patiblanco"), *Xiphopenaeus riveti* Bouvier, 1907 ("camarón titi"), *Solenocera agassizii* Faxon, 1893 ("camarón fidel"), *Heterocarpus vicarius* Faxon, 1893 ("camarón camello" or "camarón camellito"), and *H. affinis* Faxon, 1893 ("camarón real" or "camarón camellón"). According to INCOPESCA (A. Chacón, 2009, *pers. com.*), between 1995 and 2005, the annual shrimp landings along the Pacific coast were distributed as follows: *S. agassizii* 27.7%; *P. occidentalis*, *P. stylirostris*, and *P. vannamei* 20.0%; *H. vicarius* 16.9%; *P. brevirostris* 15.0%; *X. riveti* 10.3%; and *H. affinis* 9.9%.

Shrimp trawling in Costa Rica is restricted to the Pacific coast of the country, and the principal landing dock for the shrimp trawling fleet is the city of Puntarenas, Golfo de Nicoya, central Pacific. The marine fishery resources in Costa Rica are administrated by the "Instituto Costarricense de Pesca y Acuicultura" (INCOPESCA), which was founded in 1994. According to this institution, the semi-industrial fishery fleet consists of 72 registered fishing vessels; however, only 52 of them are currently active and have valid fishing licenses. A total of 45 vessels can operate in coastal marine waters and seven in the deepwater fishery (Bolaños, 2005). Trawlers fishing for shallow water shrimp need to use a Turtle Excluder Device (TED), whereas no such device is obligatory for deepwater fishery in Costa Rica. A detailed description of the type of bottom trawl net used in the Costa Rican semi-industrial shrimp fishery is provided by Bolaños (2005). All vessels operate with two trawling nets (Fig. 3), and most nets have a distance of 44.5 mm between knots (Bolaños, 2005).

EXPLOITED DEEPWATER SPECIES

Currently, there are three deepwater decapod species that are of commercial interest in Costa Rica: the two pandalid shrimps, *Heterocarpus affinis* and *H. vicarius*, and *Solenocera agassizii* (Decapoda: Penaeoidea: Solenoceridae).

Heterocarpus affinis (Fig. 4)

Information regarding this species, locally known as "camarón camellón" or "camarón real", is extremely

Figure 3. A commercial shrimp trawler used for the deepwater fishery in Costa Rica. Photo: I.S. Wehrtmann.

Figura 3. Barco camaronero comercial utilizado en la pesca en aguas profundas en Costa Rica. Foto: I.S. Wehrtmann.

Figure 4. Lateral view of *Heterocarpus affinis* ("camarón camellón"). Photo: I.S. Wehrtmann.

Figura 4. Vista lateral de *Heterocarpus affinis* ("camarón camellón"). Foto: I.S. Wehrtmann.

scarce. Its known geographical distribution ranges from the Golfo de California, Mexico, to approximately 8º43'S, Peru (Hendrickx & Wicksten, 1989). The shrimp is known to occur between 760 and 1240 m depth (Hendrickx & Wicksten, 1989; Hendrickx, 2003). The species is considered to be a potential fishery resource in Peru (Hendrickx & Wicksten, 1989) and can attain maximum sizes of 153 mm TL (total length) (Hendrickx, 2003).

When considering the annual landings, despite its large size, *H. affinis* is the least important deepwater species in Costa Rica (Fig. 5). At the beginning of the registration of annual shrimp landings in Costa Rica, the data of *H. affinis* were pooled with those of *H. vicarius*. Starting in 1995, their data were separated. Landings of *H. affinis* increased steadily between 1995 and 1999; however, the highest annual landings were recorded in 2003 with 225,277 kg (Fig. 6). Subsequently, landings decreased drastically and, since 2006, no more landings have been recorded. As far as we know, *H. affinis* is not currently commercially exploited in Costa Rica.

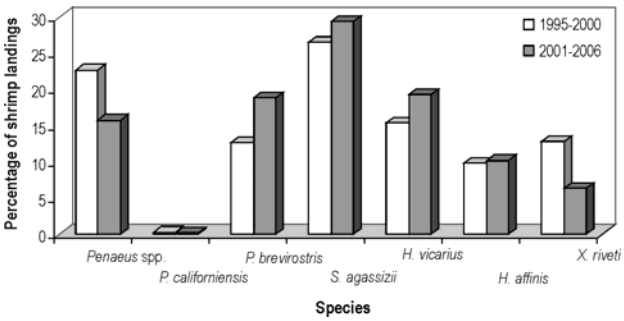

Figure 5. Costa Rica: percentages of shrimp landings for each species or group of species (*Penaeus* spp.: *P. occidentalis*, *P. stylirostris*, and *P. vannamei*) during the periods of 1995-2000 and 2001-2006 (data from INCOPESCA).

Figura 5. Costa Rica: porcentajes de las capturas de camarones por especie o grupo de especies (*Penaeus* spp.: *P. occidentalis*, *P. stylirostris* y *P. vannamei*) durante los períodos de 1995-2000 y 2001-2006 (datos de INCOPESCA).

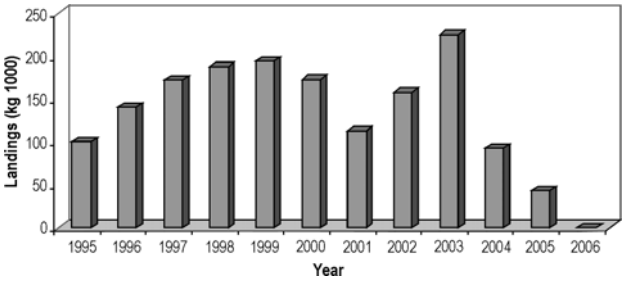

Figure 6. Annual landings (1995-2006) of *Heterocarpus affinis* ("camarón camellón") from the Pacific of Costa Rica (data from INCOPESCA).

Figura 6. Capturas anuales (1995-2006) de *Heterocarpus affinis* ("camarón camellón") a lo largo del Pacífico de Costa Rica (datos de INCOPESCA).

Heterocarpus vicarius (Fig. 7)

The geographic distribution of this species, locally called "camarón camello" or "camarón camellito", ranges from the Golfo de California (Mexico) to Panama (Holthuis, 1980). The bathymetric distribution covers the range from 73 to 550 m (Holthuis, 1980); however, in Costa Rica, this species is commercially fished mainly between 200 and 350 m depth, partly co-occurring with the other deepwater species of commercial interest, *S. agassizii*. According to Holthuis (1980), *H. vicarius* reaches a maximum size of 110 mm TL and 29 mm carapace length (CL). Data from an ongoing monitoring program in Costa Rica revealed a sex proportion of 1:1 (n = 30,106); however, in January, February, and March, females were dominant (I.S. Wehrtmann, *unpubl. data*). Ovigerous females can be found year-round; however, elevated percentages of egg-bearing females (> 40%) generally occur between June-July and September-October.

Information concerning the annual landings of *H. vicarius* in Costa Rica has been collected since 1995; previously, the data from *H. affinis* and *H. vicarius* were put together, making it impossible to separate the annual production of these two species. Considering the period between 1995 and 2006 (Fig. 8), annual *H. vicarius* landings were highest in 1996 and 1997 with 539,101 kg and 422,940 kg, respectively. Landings dropped to a low in 1999 and then increased continuously until 2003, reaching 316,745 kg. After a new drop in 2005, production increased in 2006 to 211,485 kg. Data from The Rainbow Jewels S.A., Puntarenas, Costa Rica (R. Diers, *unpubl. data*) indicated a considerable decrease to less than 100,000 kg in 2007. Currently, *H. vicarius* landings are negligible, and the commercial deepwater fishery focuses on *S. agassizii*. In fact, *H. vicarius* seems to have disappeared during the last two years from the fishing grounds between 150 and 400 m depth. This alarming situation raises the question as to whether this is the result of an overexploitation of the resource, if the species migrated to other (deeper?) areas, or if other environmental factors have caused or contributed to the almost complete disappearance of *H. vicarius* in the fishing area reported in our study.

Figure 9 depicts the monthly landings of *H. vicarius* in 2004 (a "good" year) and 2007 (a "bad year"). In 2004, the highest landings occurred between February and August, representing 81% of the annual landings. In February and March alone, 36% of the yearly landings were obtained.

Solenocera agassizii (Fig. 10)

Three species of the genus *Solenocera* have been reported from the Pacific coast of Costa Rica (Hendrickx, 1995; Vargas & Wehrtmann, 2009): *S. agassizii*, *S. mutator* Burkenroad, 1938, and *S. florea* Burkenroad, 1938. Locally known as "camarón fidel", *S. agassizii* is the most abundant and largest species of the genus along the Pacific coast of the Americas. According to Hendrickx (1995), males and females can attain sizes up to 115 and 140 mm TL, respectively. However, females can reach even larger sizes in Costa Rica (154 mm; I.S. Wehrtmann, *unpubl. data*). The species is commercially exploited in Costa Rica and Panama, and important quantities have also been reported from the coast of Nicaragua (Holthuis, 1980; Hendrickx, 1995; Puentes *et al.*, 2007). The species can be found around the external portion of the continental shelf down to 384 m and prefers soft bottoms (Hendrickx, 1995). In Costa Rica, the species is fished mainly between 150 and 350 m depth (I.S. Wehrtmann, *unpubl. data*).

In general, *S. agassizii* is the most important species in the commercial deepwater shrimp fishery in Costa Rica. From 1995 to 2000 and 2001 to 2006, this species comprised 27% and 29%, respectively, of all reported shrimp landings (Fig. 5). When revising the available historical data for this species, by far the highest yearly landing was observed in 1986 with 2.6 x 10^6 kg. Subsequently, the landings dropped to values well below 0.5 x 10^6 kg, with the exceptions of the years 1994, 1995, and 2005 (Fig. 11). Preliminary data for the years 2006 and 2007 indicate a considerable reduction of *S. agassizii* landings to roughly 0.25 x 10^6 kg per year (I.S. Wehrtmann, *unpubl. data*). Figure 12 compares the monthly landings of *S. agassizii* in 2004 and 2007, a "good" and a "bad" year, respectively, for the fishery of the species. In 2004, monthly landings increased continuously from July to October, whereas the lowest landings were observed in March and April.

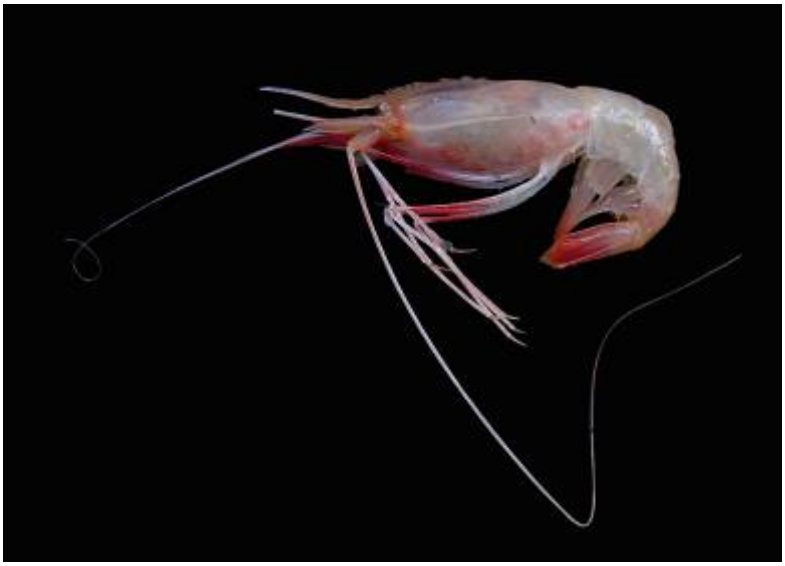

Figure 7. Lateral view of *Heterocarpus vicarius* ("camarón camello"). Photo: I.S. Wehrtmann.
Figura 7. Vista lateral de *Heterocarpus vicarius* ("camarón camello"). Foto: I.S. Wehrtmann.

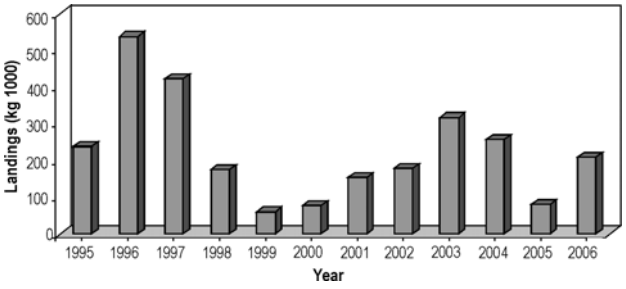

Figure 8. Annual landings (1995-2006) of *Heterocarpus vicarius* ("camarón camello") in the Pacific of Costa Rica (data from INCOPESCA).

Figura 8. Capturas anuales (1995-2006) de *Heterocarpus vicarius* ("camarón camello") a lo largo del Pacífico de Costa Rica (datos de INCOPESCA).

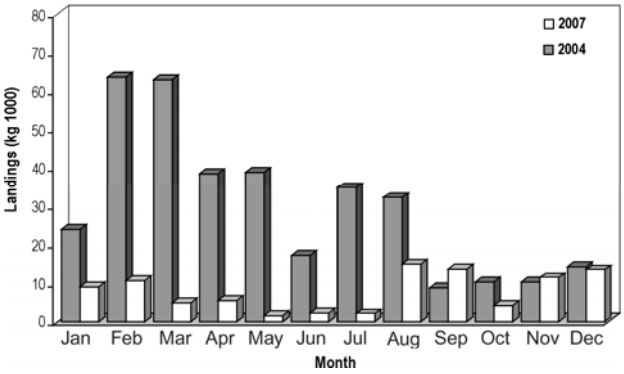

Figure 9. Monthly landings of *Heterocarpus vicarius* ("camarón camello") in 2004 and 2007 (data from The Rainbow Jewels S.A., Puntarenas, Costa Rica)

Figura 9. Capturas mensuales de *Heterocarpus vicarius* ("camarón camello") en los años 2004 y 2007, con base en datos facilitados por The Rainbow Jewels, S.A. (Puntarenas, Costa Rica).

The situation in 2007 did not reveal a clear pattern, 40% of the yearly landings were obtained in May, July, and December.

RESEARCH ON DEEPWATER RESOURCES IN COSTA RICA

Costa Rica does not have any research vessel, thus it is not surprising that most marine research carried out so far in this country concerns the flora and fauna of shallow water habitats (Wehrtmann *et al.*, 2009). Despite of its economic importance for Costa Rica, surprisingly little information is available concerning the different fishery and biological aspects of the shrimp resources commercially exploited along the Pacific coast. Most studies concerning decapods focus on shallow water penaeid shrimp (Tabash & Palacios, 1996; Tabash-Blanco & Chávez, 2006; Tabash-Blanco, 2007) and the blue crab (*Callinectes arcuatus* Ordway, 1863) (Fischer & Wolff, 2006). Additionally, Campos (1983) reported on discarded by-catch of fish and other organisms from the commercial shrimp fishery in the Golfo de Nicoya and Golfo de Papa-

Figure 10. Lateral view of *Solenocera agassizii* ("camarón fidel"). Photo: I.S. Wehrtmann
Figura 10. Vista lateral de *Solenocera agassizii* ("camarón fidel"). Foto: I.S. Wehrtmann

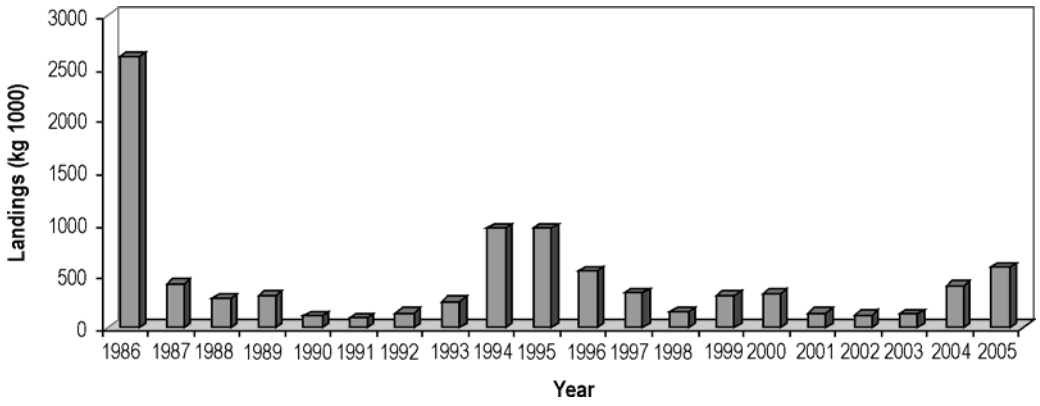

Figure 11. Yearly landings (1986-2005) of *Solenocera agassizii* ("camarón fidel") in the Pacific of Costa Rica (data from INCOPESCA).
Figura 11. Capturas anuales (1986-2005) de *Solenocera agassizii* ("camarón fidel") a lo largo del Pacífico de Costa Rica (datos de INCOPESCA).

gayo, central and northern Pacific of Costa Rica, respectively.

Our knowledge on deepwater resources in Costa Rica is even more limited. In fact, fishery-biological studies of these resources started in the year 2004, when the private fishery sector (Ristic AG, Germany, and The Rainbow Jewels S.A., Costa Rica) together with the Universidad de Costa Rica initiated a joint effort to investigate the commercially exploited species *H. vicarius* and *S. agassizii* in order to facilitate the development of a management plan for a sustainable fishery of these resources. This so-called "Public-Private-Partnership" (PPP) project, financed mainly through the German Federal Ministry for Economic Cooperation and Development (BMZ) and the participating private companies, permitted scientists to have regular access to samples taken between 150 and 400 m depth. More recently, a regional initiative between Costa Rica, Nicaragua, and El Salvador aimed at studying the deepwater resources and their sustainable use along the Pacific of Central America was funded and coordinated by the Consejo Superior Universitario Centroamericano (CSUCA), the German Association for Technical Cooperation (GTZ), and the University

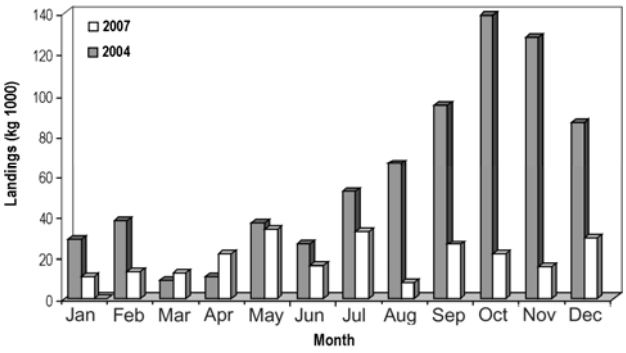

Figure 12. Monthly landings of *Solenocera agassizii* ("camarón fidel") in 2004 and 2007, based on data provided by The Rainbow Jewels, S.A. (Puntarenas, Costa Rica).

Figura 12. Capturas mensuales de *Solenocera agassizii* ("camarón fidel") en los años 2004 y 2007, con base en datos facilitados por The Rainbow Jewels, S.A. (Puntarenas, Costa Rica).

of Kassel (Germany). This project forms part of the Program University–Private Sector for Sustainable Development (PUEDES). These collaborative efforts between universities and the fishery sector have allowed the collection of valuable material, now deposited, e.g., in the Museo de Zoología of the Universidad de Costa Rica. Moreover, many students have benefited from the access to trawling vessels and the collected samples that allowed them to develop their own research projects and/or obtain important material for their theses. One example of such collaboration is the study on the diet composition of the threadfin anglerfish *Lophiodes spilurus* (Garman, 1899), one of the most abundant fish associated with the deepwater fishery in Costa Rican Pacific (Espinoza & Wehrtmann, 2008). Their results revealed that *L. spilurus* feeds exclusively on crustaceans (Decapoda and Stomatopoda) and benthic teleost fish along the Pacific of Costa Rica. However, our understanding of the trophic dynamics of deepwater ecosystems is far from complete.

BY-CATCH AND DISCARDS

Commercial bottom trawling is considered to be one of the primary causes of physical perturbation to the seabed on the continental shelf and upper slope (Watling & Norse 1998; Bozzano & Sardà, 2002). In general, these shrimp fishing gears are poorly selective; they catch and retain large quantities of non-target species, so-called "by-catch" (Andrew & Pepperell, 1992; Hall *et al.*, 2000). Shrimp trawl fisheries, and tropical shrimp fisheries in particular, have been identified as the single greatest source of discards, accounting for 27.3% of estimated total discards (Kelleher, 2005).

In Costa Rica, practically the entire by-catch of the deepwater fishery is discarded. Even species which are of commercial value in other Central American countries ((e.g., the squat lobster *Pleuroncodes planipes* (Stimpson, 1860)) are thrown away.

The crustacean fauna associated with the deepwater fishery of *H. vicarius* in the Pacific of Costa Rica was studied by Wehrtmann & Echeverría-Sáenz (2007). They encountered 28 decapods and two stomatopod species. Apart from the co-occurring target species *S. agassizii*, the most common by-catch species were *Squilla biformis* Bigelow, 1891 (Squillidae), *Plesionika trispinus* Squires & Barragan, 1976 (Pandalidae), and *Pleuroncodes* sp. (Galatheidae), reaching maximum total catch percentages of 81.5%, 91.8%, and 99.6% of individual catches, respectively. Crustaceans were predominant in all three depth ranges (200-249 m, 250-300 m, 301-350 m), and the percentage of fish as part of the total catch decreased continuously and inversely with depth from 16% (200-240 m) to 8% (301-350 m).

Figure 13 depicts the by-catch composition associated with the deepwater shrimp fishery along the Pacific coast of Costa Rica from 2004 to 2008. The most striking result is the continuous decrease and almost complete disappearance of one of the target species, *H. vicarius*; at the same time, the portion of stomatopods increased steadily, reaching more than 53% in 2008. Interestingly, the increase of stomatopods was not restricted to the Costa Rican fisheries, but was also observed in the *Pleuroncodes* fishery in El Salvador (F. Chicas & N. Hernández, *unpubl. data*). More studies are needed to document and to understand the processes related to the observed changes in the species composition of the deepwater fauna along the Pacific coast of Central America. Moreover, the steady increase of stomatopods as part of the by-catch fauna as well as the apparent disappearance of *H. vicarius* require further attention (Fig. 13).

FISHERY MANAGEMENT

The management of Costa Rican marine fishery resources is the responsibility of the "Instituto Costarricense de Pesca y Acuicultura" (INCOPESCA). This institution has the legal authority to regulate both (1) the sustainable use of hydrobiological resources and (2) the protection of related ecosystems. However, the Ministry of Environment, Energy, and Telecommunications (MINAET) is responsible for the design and establishment of protected areas and has jurisdiction

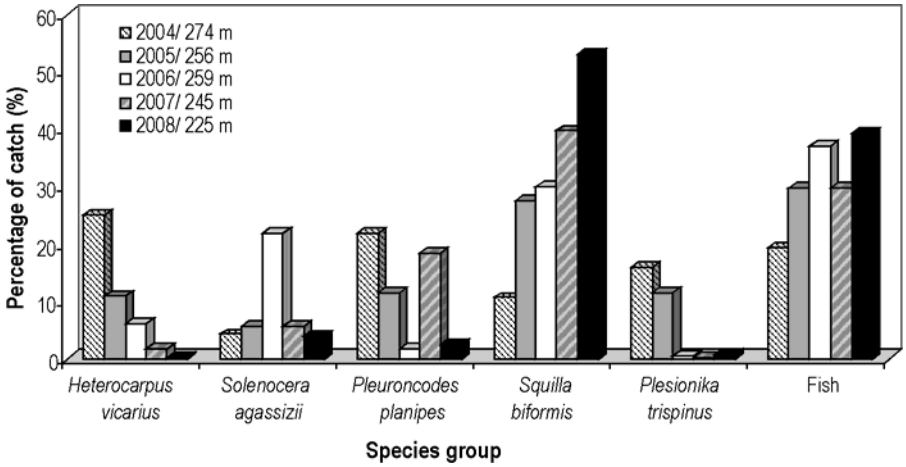

Figure 13. Catch composition of the deepwater fishery in Costa Rica from 2004 to 2008, indicating the average fishing depth per year.

Figura 13. Composición de las capturas de la pesca de aguas profundas en Costa Rica durante los años 2004-2008, indicando la profundidad promedio de pesca por año.

over the marine resources within marine protected areas. Finally, the National Coast Guard is responsible for the protection of the marine resources and the enforcement of fishery management related regulations in the EEZ of Costa Rica. According to Quesada-Alpízar (2006b), the lack of an efficient legislation has limited INCOPESCA's management capabilities, which, in turn, has led to increased deterioration of marine resources.

As far as we know, no management plan has been implemented by INCOPESCA for the use of the deepwater resources in Costa Rica. In fact, due to the numerous limitations confronting INCOPESCA (e.g., lack of adequate infrastructure and human resources), information concerning biological-fishery aspects of these resources has been generated so far exclusively by the Universidad de Costa Rica in close collaboration with the private sector (Wehrtmann & Echeverría-Sáenz, 2007). The statistics of the annual landings of deepwater shrimp are based upon the data provided by the fishery sector; since INCOPESCA does not have the manpower to verify these data, the fishery statistics presented by this institution may not necessarily reflect the real production of the different commercially exploited species.

CONCLUSIONS AND RECOMMENDATIONS

The situation of all three commercially exploited deepwater species (*H. affinis*, *H. vicarius*, and *S. agassizii*) in Costa Rica is alarming. Currently, the commercial fishery for the two pandalid shrimp, *H. affinis* and *H. vicarius*, has stopped. This has not been the result of an adequate and consequent management plan, but is related to the near disappearance of these resources within the current fishing grounds that forced the fishery sector to move on to other resources or to abandon the fishery, provoking important social and economical consequences. Together with their partners from the fishery sector and based on the data generated by this collaboration, during recent years, the Universidad de Costa Rica officially informed INCOPESCA twice about the alarming situation of the deepwater fishery and suggested a temporary closure of the fishery of selected species. Unfortunately, these suggestions have not been implemented by the national fishery authority.

We see an urgent need to join forces between the private fishery sector, the governmental institutions (INCOPESCA, MINAET), non-governmental organizations interested in the sustainability of the marine ecosystem, and the academic sector. Such a joint effort is necessary because the special life history characteristics of these deepwater species make them vulnerable to depletion and they have only a limited capacity to recover from over-exploitation (Cheung *et al.*, 2005; Morato *et al.*, 2006). Therefore, solid information about the life history parameters of the exploited species is needed. Such basic information is essential for the development and the implementation of any management measure (Polidoro *et al.*, 2008). The recent foundation of the Unidad de Investigación Pesquera y Acuicultura (UNIP) at the Universidad de

Costa Rica (UCR), co-financed by the UCR and the fishery sector (The Rainbow Export Processing, S.A., Puntarenas), is certainly a promising step in the correct direction. Moreover, the UNIP will play a key role in the formation of much needed qualified personal to carry out the scientific analyses and to support the development and monitoring of adequate management programs.

It is recommended that all relevant stakeholders establish, as a joint effort, a monitoring program of the deepwater resources and associated by-catch. Moreover, the use of more selective fishing methods should be encouraged in order to reduce the amount of discarded biomass as well as to study possibilities for an adequate (commercial) use of the discards. At the same time, the establishment of temporary and spatial fishery regulations should be considered to protect the threatened deepwater resources of Costa Rica.

The Costa Rican fishery authorities are encouraged to revise the legal framework of the legislation and fishery management of the deepwater shrimp *Heterocarpus reedi* Bahamonde, 1955 in Chile, a species with a similar ecology to *H. vicarius* (Roa & Ernst, 1996). The Chilean management strategy includes public auctions of fishery quotas, accompanied by a scientific research program that acts as a basis for establishing future fishery quotas for the target species. The lack of efficient control mechanisms limits the implementation of any management plan in Costa Rica. However, the national fishery authorities have the responsibility to protect the marine resources and need to put into practice adequate measures to avoid uncontrolled overfishing of these valuable deepwater resources along the Pacific coast of Costa Rica.

ACKNOWLEDGMENTS

The study of the deepwater fishery in Costa Rica would not have been possible without the excellent collaboration of The Rainbow Jewels, S.A., Puntarenas, which allowed us to collect samples with their commercial shrimp trawlers. We would like to thank Ronny Gründler and René Diers, the previous and current general manager of the company, respectively, for their tremendous support during all these years. A special thanks goes to the crews of the commercial shrimp trawlers of this company, especially to the captain of the boat "Onuva", Rigoberto Villalobos Cruz. Much of the research formed part of a so-called Public-Private Partnership project about the development of standards for sustainable deepwater shrimp fisheries in Pacific Costa, financed by the German Federal Ministry of Economic Cooperation and Development (BMZ), the company Ristic AG (Oberferrieden, Germany), and the Universidad de Costa Rica (project V.I. No. 111-A4-508). Adam Chacón (INCOPESCA) facilitated unpublished shrimp fishery data, which is greatly appreciated. Catalina Benavides (UNIP) helped us with the preparation of Figure 2. Finally, we are most grateful to the students and assistants (Silvia Echeverría, Fresia Villalobos, Jaime Nivia, Patricio Hernáez, Jeffry Ortiz, Tayler Clarke, Juliana Herrera, Edgar Villegas, just to mention some) who helped during the years with the collection and processing of the deepwater samples. To all of them: ¡Muchas gracias! Finally, we appreciated the constructive comments of the referees.

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Received: 5 June 2009; Accepted: 27 August 2009

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