Chapter 5

# Deep-Water Sharks, Rays, and Chimaeras of Brazil

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69471

**Abstract**

The deep-water fishery in Brazil is currently in expansion due to depletion of most neritic economic species. This increasing deep-water effort brings concern on the bycatch impact, its specific composition, the need for capture's evaluation and development of bycatch reduction devices. The impact is particularly aggressive on deep-water elasmobranchs, which have an extreme ecological k-strategy due to their reproductive constraints (lower fecundity and late first maturity age). Scientific deep-water surveys and intensive research programs (REVIZEE) along the past decade indicate that Brazilian elasmobranch diversity is higher than previously imagined. However, the deep-water fishery threatens this poorly known community of sharks and rays on the Brazilian continental slope as they become bycatch of a fast-growing and uncontrolled fishery. The recent study case of the monkfish (*Lophius gastrophysus*) fishery dynamics, well presented and discussed by the Brazilian scientific community, provided evidence of the need of bycatch-specific monitoring programs and fast-response fishery regulations. The present work discusses the Brazilian deep-water elasmobranch bycatch problem under the light of its biological diversity and completely unknown population status. Suggestions and management considerations are presented in order to coordinate and manage the establishment and growth of this deep-water fishery in Brazil.

**Keywords:** elasmobranch, fish, continental slope, biodiversity, demersal, Chondrichthyes

## 1. Introduction

The development and use of deep-water fishing gears (bottom trawl, bottom longline, gillnets and pot traps) along the Brazilian continental slope have increased significantly after the depletion of the majority of valuable coastal fishing resources over the past decades [1–5]. However, this search for new fishing grounds and change of fishing habits sometimes occurs

suddenly in a "gold rush" and spasmodically as old resources collapse and new resources are discovered and/or extreme catch variations are reported [3, 6–10]. This pioneer new fishery is characterized by excessive investments encouraged by regulations and subsidies [3, 11–13], leading great part of the local fleet to target mostly a single valuable species for a distinct foreign market. As a result, this particular resource sustains high catches for a short time, usually 2 or 3 years, followed by a complete economic collapse [6, 9]. This fishing behavior and voracity led researchers to find themselves in a cat-and-mouse game where fishing resources are exploited before the scientific community, which is aware of it or even far from an available population management data base [7]. Probably even more serious is the capture of a large number of bycatch species, especially those of smaller size, highly represented and particularly with a population dynamics sensitive to fishery mortality, such as sharks, rays, and sea birds [2, 14–16].

The Brazilian deep-water elasmobranch diversity is poorly known only by occasional records based on commercial and scientific surveys, mostly as part of the recent Brazilian Program for Evaluation of the Living Resources in the Exclusive Economic Zone (REVIZEE). A recent increase of deep-water research along the Brazilian continental slope in the past decades [1995–2007] has revealed a great number of new species or records of elasmobranch fishes [17–31], which is changing the marine biogeographic relevance of the Neotropical realm for this group of vertebrates. Nineteen species were recorded for the first time in Brazil or described for the continental slope habitat over the past 15 years. The list of species known to occur on the Brazilian continental slope increases significantly every year and suggests that the total number of species is still beyond the current knowledge [17, 18, 32–36]. Several recent records were at the genus level (*Somniosus, Dalatias, Cirrhigaleus, Centrophorus, Apristurus, Galeus, Parmaturus, Pseudotriakis, Mitsukurina, Benthobatis, Dactylobatus, Cruriraja, Breviraja*, and *Malacoraja*) and four new families were recorded for the first time (Anacanthobatidae, Pseudotriakidae, Centrophoridae, and Mitsukurinidae), [*q.v*. 17, 27, 37–39] (**Figure 1**). Currently, several deep-water species are under description or under review process (e.g., *Scyliorhinus* sp. B and *Dipturus* sp. A and sp. B, *Parmaturus* cf. *campechiensis* Springer 1979). These findings are evidence of unevaluated deep-water species diversity and bring concern on the possible near-future development of deep-water fisheries where scientific research is still badly needed.

Recent deep-water scientific trawls off the north and southern coasts of Brazil have revealed several unexploited stocks of prawns such as *Aristeus antillensis* Milne-Edwards and Bouvier 1909 and *Aristaeopsis edwardsiana* (Johnson, 1868), and crabs of the genus *Chaceon* [38, 40–42]. Additionally, as a result, the local fleet has considered adapting the necessary gear for deep-water bottom trawl in search of these valuable crustaceans, but mostly chartered fleet landings have operated and the fishery developed mainly from 2002 to 2009 (*q.v*. [42] for a review). The area is part of the known range of distribution of species such as: *Schroederichthys tenuis* Springer 1966, *Scyliorhinus ugoi* Soares, Gadig and Gomes 2015,*Breviraja spinosa* Bigelow and Schroerder 1950, *Gurgesiella atlantica* (Bigelow and Schroeder 1962), *Dipturus* spp., *Rajella purpuriventralis* (Bigelow and Schroeder, 1962) and the recently recorded goblin shark *Mitsukurina owstoni* Jordan 1898 [17, 38, 39]. According to Asano-Filho et al. [38], about 4% (4278 kg) of the total experimental capture (kg/h) of a series of scientific trawls consisted

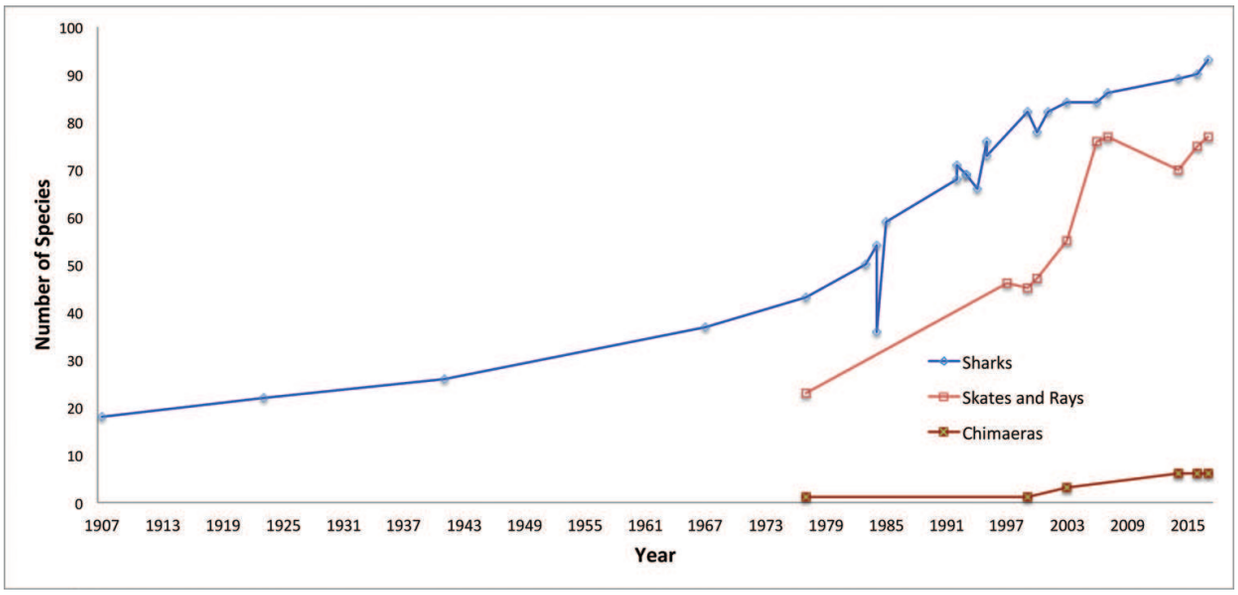


**Figure 1.** Total number of Chondrichthyes recorded along the time in Brazilian waters. This numeric compilation considered published papers, thesis and species accounts presented in scientific meetings.

of elasmobranchs. However, these authors did not consider the numeric capture per species, and since most of these species listed above are small to medium sized forms (excepting adult *Dipturus* and *Mitskurina*), the impact on the elasmobranch community may be more important than previously supposed by analyzing solely the Capture-Per-Unit-Effort (CPUE) in weight terms.

The monkfish fishery off the southern Brazil was initially established by chartered boats that introduced the deep-water net and trawl fishing technology, quickly followed by the national fleet on a smaller scale [3, 4]. This fishery along with the seasonal deep-water trawl for squids [*Loligo* sp. and *Illex argentinus* (Castellanos, 1960)] emerged fast with surprising landings that reached 4300 metric tonnes of monkfish in 2001 and 2300 tonnes of squid in 2002 [43, 44]. These landings represented a yield increase of up to 1147 and 6597% for monkfish and squid, respectively, in relation to the previous years. The "gold rush" for these resources had just started; although both groups would never reach these levels of catch again. The chartered boat program was reviewed in 2002; mainly because of the influence and research on the monkfish fishery by the scientific crew of the Universidade do Vale do Itajaí-UNIVALI. However, this fishery continues and tends to expand toward the continental slope of the north and northeast coasts of Brazil [45], that brings concern on how fast local researchers will be able to follow fisheries growth and trends.

Here we present a brief review on Brazilian deep-water Chondrichthyes and examine the risk of population collapse of untargeted and poorly recorded deep-water cartilaginous fishes captured by deep-water fisheries, particularly based on the well recorded case of the monkfish [*L. gastrophysus* (Miranda-Ribeiro, 1915)], Argentine squid (*I. argentinus*), and aristeid shrimp (*A. antillensis* and *A. edwardsiana*) fisheries off southern Brazilian coastland available data from the REVIZEE Program.

## 2. Assembling deep-water information

Deep-water species were considered as those whose captures occurred only, or at least mainly, deeper than 200 m, coincident with the continental shelf edge [46]. This definition also considers the depth distribution in the water column as many species presents a vertical migration in circadian cycles to epipelagic zones at night and deeper waters at day [47–49]. All species identification and nomenclature herein presented followed [50, 51].

All analyzed specimens were captured on the continental slope of Brazil (**Figure 2**) between depths of 130 and 1000 m, by commercial and research vessels between 1991 and 2008 using bottom longline, otter trawl, pot traps, and gillnets. Most of the results from research cruises make part of the Brazilian Program for Evaluation of the Living Resources in the Exclusive Economic Zone (REVIZEE) (1995–1998) or previous local research projects (Fundação Universidade do Rio Grande [FURG] off southern Brazil) (*q.v.* [1, 25, 52–55] for descriptions of capture methodologies). REVIZEE research cruises off the northeast and north coasts used bottom longline and crab pots and otter trawl and longline, respectively ([45] for a longline fishery description). Additional specimens were analyzed from collections at FURG, Universidade Federal Rural de Pernambuco (UFRPE), Universidade Federal do Pará (UFPA), Museu Paraense Emílio Goeldi (MPEG), Museu de Zoologia da Universidade de São Paulo (MZUSP), Universidade Federal da Paraíba (UFPB), Universidade do Vale do Itajaí (UNIVALI), and personal collections of the authors to be institutionally deposited after analysis and publication of results.

Records published in scientific literature, unpublished master and doctoral thesis or simply reported in scientific meetings (abstracts and proceedings) and project reports were also considered as reliable sources of information.

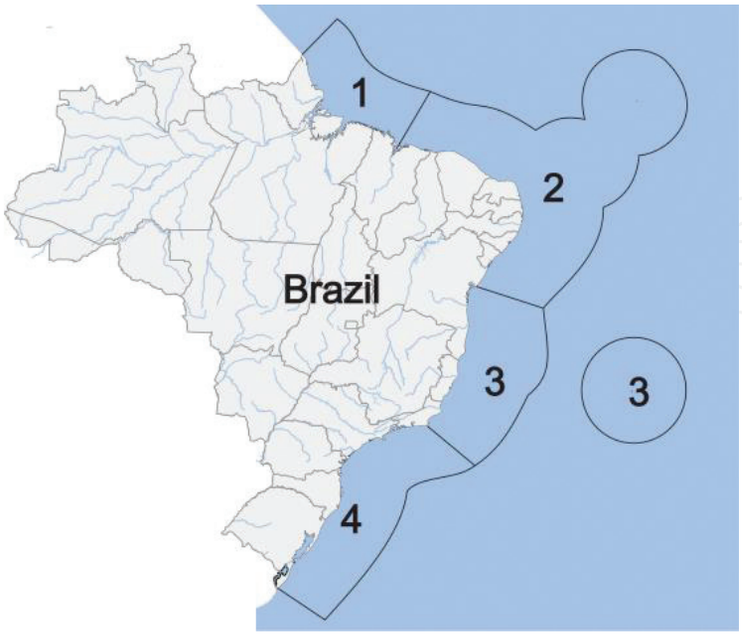


**Figure 2.** South America and Brazilian coastline as identified by the REVIZEE Program: 1. Northern Coast, 2. Northeastern Coast, 3. Central Coast and 4. Southern Coast.

Bycatch and deep-water fisheries data were based on reports by the UNIVALI research staff (http://gep.acad.univali.br and http://gep.acad.univali.br/?page=estatistica_boletins) and published annual fishery reports by the Brazilian Environmental Agency (IBAMA) (http://www.ibama.gov.br/) up to the year 2011. The gill net monkfish fishery bycatch analysis of [56] provided annual total capture of elasmobranchs and CPUE estimations for 2001.

### 2.1. Brazilian deep-water elasmobranch bycatch

Elasmobranchs are considered bycatch by most of the deep-water fisheries along the coast and, as a result they are frequently discarded or retained aboard only when the captures of target species are low [15, 43, 56–58]. The only possible retained exceptions are *Galeorhinus galeus* (Linnaeus, 1758), *Squatina* spp., *Squalus* spp., *Mustelus canis* (Mitchell, 1815) and rajids identified as "emplastro" (*e. g., Dipturus* spp., *Atlantoraja castelnaui* (Ribeiro, 1907), *Atlantoraja cyclophora* (Regan, 1903), *Atlantoraja platana* (Günther 1880) and *Rioraja agassizi* (Müller and Henle, 1841)], which may be captured by deep-water fisheries but are considered neritic resources [3, 59]. Eventually, larger species with incipient captures are often retained [*Hexanchus griseus* (Bonnaterre, 1788), *Carcharhinus* spp., *Sphyrna* spp., and others], but they represent less than 5% of all deep-water elasmobranch numeric catches. Perez et al. [58] reported a catch composition of 2.1% of chondrichthyan fishes on the deep-water shrimp fishery in 89 analyzed trawls, and concluded that the whole catch was discarded, which represented at least 1617 specimens of *Etmopterus lucifer* Jordan and Snyder, 1902 and 688 specimens of *Gurgesiella dorsalifera* McEachran and Compagno, 1980. However, some frequently captured small sized species may be unrecorded or misidentified by most of onboard observers (Chartered Fleet Observers Program-Ministry of Agriculture and UNIVALI) and fisheries monitoring programs. These species are mostly treated in generic terms such as "caçonetes" and "cações," or "raias" and "emplastro" (small sharks and rays, respectively) and even hardly considered or identified as bycatch in deep-water fisheries [60]. These groups also include rare and deep-water species such as: *Galeus mincaronei* Soto 2001, *Apristurus* spp., neonates of *Scyliorhinus, Schroederichthys* and *Dipturus* spp., *Etmopterus* spp., *Centrocymnus owstoni* Garman 1906 (previously identified as *C. cryptacanthus* Regan 1906), *Parmaturus* cf. *campechiensis, Cruriraja* sp., *Bathyraja schroederi* (Krefft, 1968) and *Rajella sadowskyii* (Krefft and Stehmann, 1974) (**Table 1**). The lack of precise identification leads to an underestimation of the total capture of the group, especially those highly numbered smaller forms frequently discarded at sea. Some rare and unfamiliar species to most fishery scientists and students were also discarded or unreported along research programs, such as the false catshark *Pseudotriakis microdon* Capello 1868 and the slender catshark *S. tenuis* off northeast and north Brazil, respectively [17, 37, 61].

Scientific surveys usually provide the most reliable source of information to estimate commercial fisheries' bycatch composition as all captured specimens are considered in the analysis and not discarded at sea. However, this bycatch level is frequently much underestimated due to the larger effort and efficiency of commercial vessels in comparison to scientific cruises. The northeastern and central surveys of the REVIZEE program developed experimental bottom longline sets twice a year (November) from 1997 to 1999. These catches presented a chondrichthyan dominance (60% of total catch) [62], and some numbered species suggest that elasmobranchs may become a large component of the bycatch in a future deep-water fishery in the area. Spiny

| | Otter Trawl | Gill Net | Longline |
|---|---|---|---|
| **Sharks** | | | |
| *Hexanchus griseus* | | X | X |
| *Heptranchias perlo* | X | | |
| *Echinorhinus brucus* | X | | X |
| *Somniosus antarcticus* | X | | |
| *Somniosus pacificus* | X | | |
| *Centroscymnus coelolepis* | X | | |
| *Centroscymnus owstoni* | X | | X |
| *Zameus squamulosus* | X | | |
| *Etmopterus pusillus* | X | | |
| *Etmopterus lucifer* | X | | |
| *Etmopterus bigelowi* | X | | X |
| *Etmopterus granulosus* | X | | |
| *Etmopterus hillianus* | X | | |
| *Etmopterus gracilispinis* | X | | |
| *Euprotomicroides zantedeschia* | X | | |
| *Euprotomicrus bispinatus* | | | |
| *Isistius brasiliensis* | X | | |
| *Isistius plutodus* | | | |
| *Dalatias licha* | | | X |
| *Squaliolus laticaudus* | X | | |
| *Squalus acanthias* | X | X | X |
| *Squalus bahiensis* | X | | X |
| *Squalus albicaudus* | X | | X |
| *Squalus quasimodo* | X | | X |
| *Squalus lobularis* | X | | X |
| *Cirrhigaleus asper* | X | | X |
| *Centrophorus granulosus* | | | X |
| *Deania profundorum* | X | | |
| *Apristurus parvipinnis* | X | | |
| *Apristurus profundorum* | X | | |
| *Apristurus manis* | X | | |
| *Galeus mincaronei* | X | | X |

| | Otter Trawl | Gill Net | Longline |
|---|---|---|---|
| *Parmaturus cf. campechiensis* | X | | |
| *Schroederichthys saurisqualus* | X | | X |
| *Schroederichthys bivius* | X | | X |
| *Schroederichthys tenuis* | X | | |
| *Scyliorhinus haeckelii* | X | | X |
| *Scyliorhinus ugoi* | X | | X |
| *Scyliorhinus cabofriensis* | X | | |
| *Scyliorhinus* sp. B | X | | |
| *Mustelus canis* | X | X | X |
| *Pseudotriakis microdon* | | | X |
| *Mitsukurina owstoni* | X | | |
| *Squatina* sp. A | X | X | X |
| *Squatina* sp. B | X | | |
| **Rays** | | | |
| *Benthobatis kreffti* | X | | |
| *Tetronarce puelcha* | X | X | |
| *Tetronarce* sp. A | X | | |
| *Dactylobatus clarkii* | X | | |
| *Amblyraja frerichsi* | X | | |
| *Breviraja nigriventralis* | X | | |
| *Breviraja spinosa* | X | | |
| *Dactylobatus clarkii* | X | | |
| *Dipturus bullisi* | X | | |
| *Dipturus* cf. *garricki* | X | | |
| *Dipturus leptocaudus* | X | X | X |
| *Dipturus mennii* | X | X | X |
| *Dipturus teevani* | X | | |
| *Dipturus* sp. A | X | X | X |
| *Dipturus* sp. B | X | | X |
| *Malacoraja obscura* | X | | |
| *Rajella fuliginea* | X | | |
| *Rajella purpuriventralis* | X | | |
| *Rajella sadowskii* | X | | |
| *Zearaja chilensis* | X | | |

| | Otter Trawl | Gill Net | Longline |
|---|---|---|---|
| *Bathyraja brachyurops* | X | | |
| *Bathyraja multispinis* | X | | |
| *Bathyraja scaphiops* | X | | |
| *Bathyraja schroederi* | X | | |
| *Cruriraja rugosa* | X | | |
| *Gurgesiella atlantica* | X | | |
| *Gurgesiella dorsalifera* | X | | |
| **Chimaeras** | | | |
| *Callorhinchus callorynchus* | X | X | |
| *Hydrolagus alberti* | X | | |
| *Hydrolagus matallanasi* | X | | |
| *Hydrolagus cf. mirabilis* | X | | |
| *Harriotta raleighana* | X | | |
| *Rhinochimaera* sp. | X | | |

**Table 1.** Deep-water Chondrichthyes of Brazil.

dogfishes and spurdogs [*Squalus* spp. and *Cirrhigaleus asper* (Merrett 1973)] were the main representatives with highest CPUEs (ranging from 1.44 to 5.16 sharks/100 hooks), or a total capture of 795 specimens in six cruises. The dusky smoothhound shark *M. canis* was the second species in abundance with a total capture of 114 individuals and CPUEs that ranged from 0.12 to 2.16 (sharks/100 hooks). The total CPUE for each species is presented in **Table 2** and reveal that only *Squalus* spp., *C. asper*, and *M. canis* could be important economically and all other species would make part of the bycatch if a deep-water fishery develops in the region.

Scientific deep-water otter trawls off Itajaí, state of Santa Catarina, were able to capture about 150 specimens of the blind electric ray *B. kreffti* Rincon, Stehmann and Vooren 2001 in only three trawls [25, 34]. Commercial squid trawlers operating at the same area used to land specimens of the blind electric ray attached or grabbed by the squids and occasional researcher's selections were able to separate up to 300 specimens in one single cruise (Mazzoleni, pers. obs). High CPUE values of rare benthic fishes are strong evidence of an aggregation behavior in specific areas in search of food or for reproductive purposes. The same apparent behavior was also observed in *G. dorsalifera*, a small deep-water skate with evidences of feeding aggregation based on high CPUE values and stomach contents [63–65]. Both species are reported on commercial captures by onboard observers, but frequently not considered as relevant on fisheries management programs. In addition, their aggregation behavior, geographical restriction, and numbered catches by deep-water trawlers make these populations extremely vulnerable [66, 67].

Some species captured by deep-water surveys will be treated individually as follows.

| Species/group of species | Total number | Average CPUE (N°/100 hooks) | Depth range |
|---|---|---|---|
| *Squalus* spp.* | 795 | 2.73 | 100–500 |
| *Mustelus canis* | 114 | 0.56 | 100–400 |
| *Scyliorhinus ugoi* | 16 | 0.09 | 100–500 |
| *Heptranchias perlo* | 12 | 0.11 | 200–350 |
| *Hexanchus griseus* | 6 | 0.05 | 100–300 |
| *Echinorhinus brucus* | 4 | 0.04 | 200–250 |
| *Centrophorus granulosus* | 27 | 1.12 | 300–350 |
| *Pseudotriakis microdon* | 1 | 0.01 | 300–450 |
| *Etmopterus* spp.** | 34 | 0.18 | 100–500 |
| *Dipturus* sp. B | 6 | 0.02 | 300–500 |

* *Squalus* spp. = Mostly *S. albicaudus*, but also *C. asper*.

** *Etmopterus* spp. = *E. bigelowi* and possibly *E. pusillus*.

**Table 2.** Deep-water sharks and rays off the northeast coast of Brazil captured along six cruises of the REVIZEE Program from 1997 to 1999.

## 2.2. Deep-water sharks

***Squalus* spp**.: Spiny dogfishes along with the dusky smooth-hound (*M. canis*) are probably the most abundant sharks on the continental slope of Brazil [15, 61, 68, 69]. This genus forms a complex of species where only *Squalus acanthias* Linnaeus 1758 is constantly recorded and recognized. Other species are frequently misidentified and named as *S. mitsukurii-blainvillei* and *S. megalops-cubensis* groups or *Squalus* sp. A and *Squalus* sp. B [18, 24, 70]. Their taxonomic resolution was recently investigated [71] when four new species were described as follows: *Squalus albicaudus, S. bahiensis, S. lobularis*, and *S. quasimodo* Viana, Carvalho and Gomes 2016. According to these authors, *S. albicaudus, S. bahiensis*, and *S. quasimodo* are short-nosed dogfishes, or what was previously grouped as *S. megalops-cubensis*, while *S. lobularis* is a long-nosed dogfish, what was identified as *S. mitsukurii-blainvillei*. Northeastern dogfish specimens were limited in Viana et al. [71] analysis and a precise description on the distribution of these species is urgently needed, however, this is a long waited taxonomic review that brings light on the diversity of the genus in Brazil. Research cruises off the northeastern continental slope in search of deep-water elasmobranchs with bottom longline (15 days cruise and 1000 hooks per line set, each) usually landed 150–250 [or 10–16 ind./1000 h] dogfishes per cruise (probably *S. albicaudus* and *S. lobularis* instead of *S. cubensis-megalops* and *S. mitsukurii* Jordan and Snyder 1903, respectively) (**Figure 3**), a lower CPUE when compared to the southern deep-water gill net fishery which reported a total capture of 12,208 specimens of *S. megalops* (*S. albicaudus*) captured in 14 cruises in 2001 (872 specimens *per* cruise) [15]. Haimovici et al. [1] reported CPUEs of 32–146 ind./1000 hooks with apparent decreasing CPUEs toward the northern extreme of the sampled area (from the States of Rio Grande do Sul to Rio de Janeiro).

**Figure 3.** Specimen of *Squalus* cf. *albicaudus* captured off the northeastern continental slope along the REVIZEE program.

These large captures suggest that it is likely that these species will become commercially exploited in the near future [45].

**Cirrhigaleus asper:** The roughskin spurdog (**Figure 4**) was the third most abundant squaloid captured off the northeastern Brazilian coast by the REVIZEE program with about a hundred specimens captured in six cruises (1997–1999) [45]. This species is also reported off southeastern Brazil (State of São Paulo), but previous results indicate lower abundances than those reported at the northeast coast [2, 33, 52, 72]. Population status is unknown for this species.

***Echinorhinus brucus* (Bonnaterre 1788)**: The bramble shark is frequently reported in low numbers by deep-water bottom longliners along the coast of Brazil [61, 70, 73, 74]. The REVIZEE research cruises off northeast coast usually captured two or three large mature specimens per cruise (15 days cruise/1000 hooks per longline set) (**Figure 4**). This species is also occasionally trawled on the continental shelf off southern Brazil especially during the winter months. The deep-water gill net monitoring program for the monkfish fishery reported an estimation of 4378 specimens captured in 2001 with a CPUE of 0.55 specimens per 100 nets [15]. These bycatch levels bring concern on the conservation status of local populations of the bramble shark since there is restricted biological information on this species [75].

***Centrophorus granulosus* (Bloch and Schneider, 1801)**: This squaliform shark was recorded off the state of Sergipe at 350 m depth where twenty-seven specimens were captured in one single bottom longline set [18, 24, 61] (**Figure 3**). Unfortunately, this was the last line set of the cruise and no other specimen was captured in latter deep-water surveys. The presence of adult males and pregnant females was considered evidence of a local resident population (**Figure 4**). The unique capture suggests a deeper (more than 500 m) bathymetric distribution where scientific surveys with bottom longline were not developed. Although *Centrophorus* is considered to be of commercial importance in many regions [76–78], the Brazilian population is still unknown to the deep-water fishery and this possible stock is considered intact. However, Guallart et al. [79] considered this species particularly vulnerable to fisheries based on its low fecundity rates, long gestation periods, and late maturity.

***Etmopterus* spp**. The Brazilian lanternsharks are currently represented by six species: *E. bigelowi, E. pusillus* (Lowe, 1839), *E. gracilispinis* Krefft 1968, *E. lucifer, E. granulosus* (Günther, 1880), and *E. hillianus* (Poey, 1861) [22, 47, 75, 80–82]. Specific abundances in catches presented a latitudinal shift with *E. bigelowi* (**Figure 4**) being more abundant off the northeast coast, while *E. lucifer* was more abundantly recorded off the south/southeast coast [47, 58, 61, 70, 75, 82]. However, these differences probably resulted from different fishing gears (bottom longline vs. otter trawl). Preliminary stomach content analysis of *E. bigelowi* indicates a benthopelagic feeding habit with predominance, in frequency of occurrence, of crustaceans and cephalopods [83]. Sexual maturity happens at similar sizes for males and females from 60 to 63 cm TL [47]. Perez and Wahrlich [15] and Perez et al. [58] report that lanternsharks are completely discarded onboard.

***Apristurus parvipinnis:*** This shark is occasionally reported from deep-water bottom trawlers (deeper than 600 m) in small numbers, but frequently ignored or misidentified as small squaliforms (*Etmopterus*) due to the dark pigmentation (**Figure 4**). Captures were reported by the REVIZEE Central-Score (off the State of Bahia) and the State of Santa Catarina by commercial fleet; sometimes along with *A. profundorum* (Goode and Bean, 1896), a somewhat more sporadic and geographically restricted species [18, 31, 84, 85].

***Galeus mincaronei***: This recently described small species is reported only for a restricted area off the State of Santa Catarina at depths of about 200 meters [23, 73, 86]. Its taxonomic resolution still requires a further comparison to *G. antillensis* Springer 1979 [31], but the high level of endemism and vulnerability to deep-water fisheries (bottom longline and otter trawl) brings concern on its occurrence as a common bycatch species [87] (**Figure 4**).

***Parmaturus* cf. *campechiensis*:** This species is a rare and uncommon one in the deep-water elasmobranch assemblage. Its deeper depth range (>600 m) probably protects the local population off southern Brazil from deep-water trawlers. This species was described based on a single immature specimen off Campeche (Mexico) and the Brazilian specimens (female specimens with 410 mm TL and 440 mm TL), if identification is confirmed, probably represent the second record of the species in the world [31, 88] (**Figure 4**). At least three specimens were captured so far, but a formal re-description of the species will be published elsewhere.

***Pseudotriakis microdon***: One single female specimen (2670 mm TL and 85.5 kg TW) was captured off the State of Paraíba by a bottom longline at 450 m depth (**Figure 3**). The whole animal was discarded after being misidentified as one *Carcharhinus* sp. [17, 18, 24, 61]. Although rare in research cruises, this species may become a bycatch not reported or misidentified in an eventual deep-water longline fishery for *Lopholatilus villari* Miranda-Ribeiro 1915 and *Epinephelus itajara* (Lichtenstein, 1822).

***Mitsukurina owstoni***: The first Brazilian record was unofficially reported off Rio Grande do Sul by fisherman's descriptions and a presumed photograph of the specimen captured by a deep-water gill net in July of 2001 at 380 m depth, but the animal was discarded on board before scientific analysis. Recent deep-water trawls off the states of Amapá and Pará (north Brazil) by IBAMA as part of a deep-water survey in search of new fishery resources (Proarrasto Project) resulted in the capture of six specimens (2100–2900 mm TL) with only one single preserved

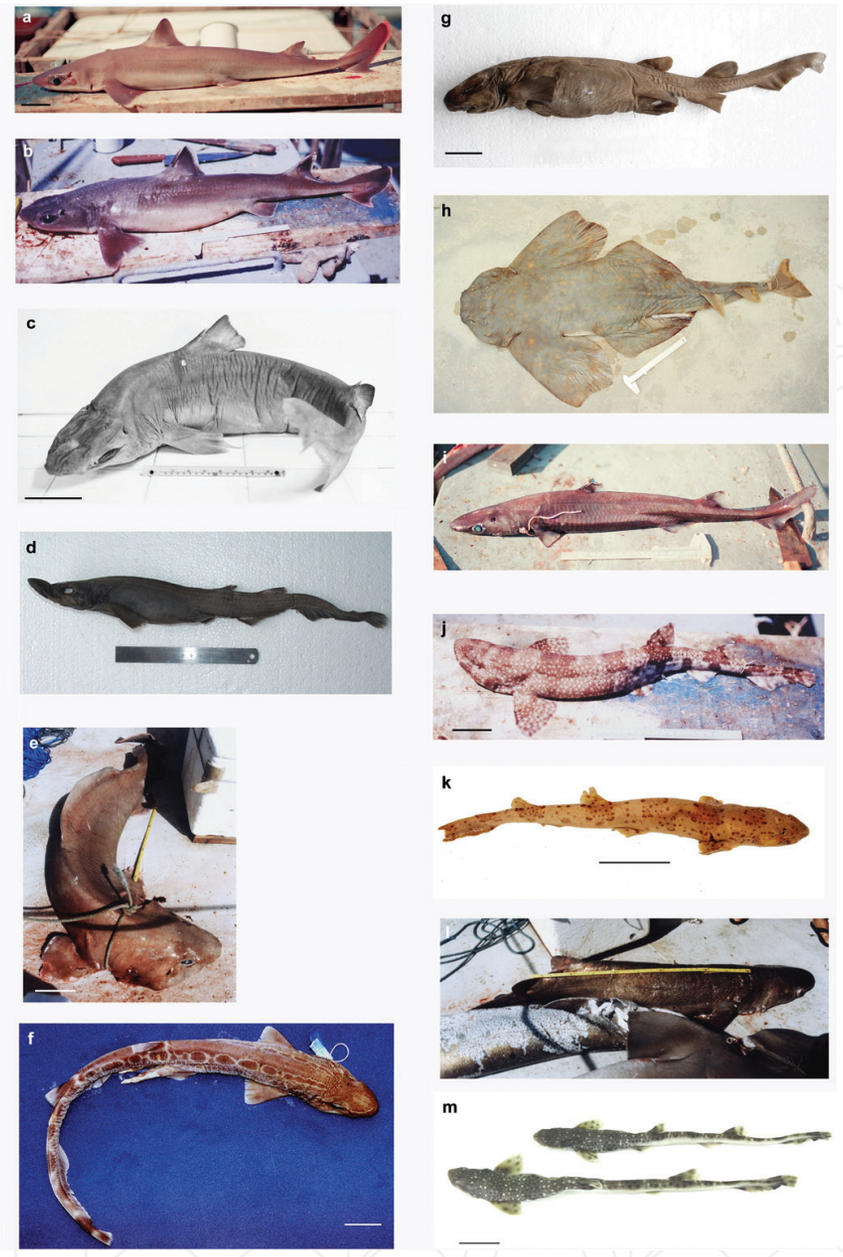


**Figure 4.** Deep-water sharks and respective scale references: (a) *Squalus* cf. *albicaudus*, 20 mm; (b) *Cirrhigaleus asper*, 150 mm; (c) *Centrophorus granulosus*, 100 mm; (d) *Apristurus parvipinnis* Springer and Heemstra 1979, 150 mm; (e) *Pseudotriakis microdon*, 300 mm; (f) *Galeus mincaronei*, 20 mm; (g) *Parmaturus* cf. *campechiensis*, 40 mm; (h) *Squatina* sp. A, 150 mm; (i) *Etmopterus bigelowi* Shirai and Tachikawa 1993, 150 mm; (j) *Scyliorhinus ugoi*, 40 mm; (k) *Scyliorhinus haeckelii* (Ribeiro, 1907) (holotype MNRJ-494), 60 mm; (l) *Echinorhinus brucus*, 1000 mm; and (m) *Schroederichthys saurisqualus* Soto 2001, 50 mm. All photographs by GR, except the false catshark and bramble sharks, which were photographed by the REVIZEE research team.

specimen (female 1040 mm TL, the smallest of all captured animals) [27, 28, 38]. All other specimens were discarded without further scientific analysis. More recently in 2008, a large mature male (3152 mm TL and 99 kg total weight] was captured in depths of 700–1000 m off the state of Rio de Janeiro by a chartered boat for deep-water shrimp (**Figure 5**) [39].

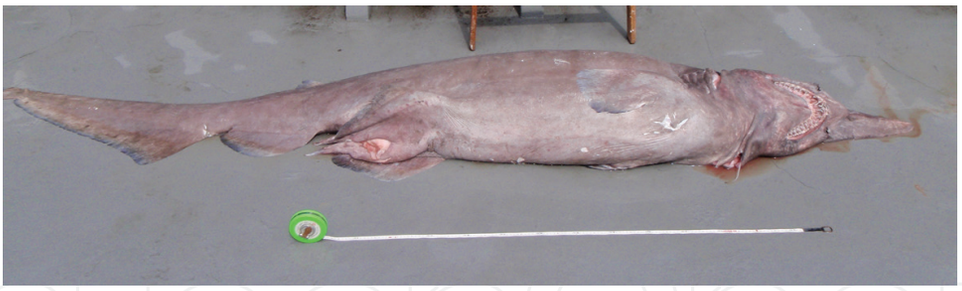

**Figure 5.** *Mitsukurina owstoni* male specimen with 3152 mm TL captured off Rio de Janeiro in 2008.

***Schroederichthys saurisqualus*** and ***S. tenuis***: The recently described catshark *S. saurisqualus* is endemic to southern Brazil with higher captures between the states of Paraná and Rio Grande do Sul. This species presents no economic value and is discarded on board [15]. *S. saurisqualus* is commonly captured by trawlers, longliners and even gill nets in waters deeper than 200 m (**Figure 4**). The slender catshark *S. tenuis* is endemic to the northern coast and has occasional catches on the continental slopes of the states of Amapá and Pará [28, 37, 88]. Both species were captured during the research surveys of the REVIZEE Program and their population impact due to deep-water fishery is currently unknown, but their high endemism level is an additional component of concern.

***Scyliorhinus haeckelii***: The recent increased interest in the freckled catshark *S. haeckelii* meat has changed its bycatch status to an occasionally commercialized species by trawlers working on the continental shelf off the state of São Paulo. This interest occurs when other more economic species are not present in the captures and catsharks may be processed as fish filets by fishing industries of Santos (southeastern coast). Perez and Wahrlich [15] reported the capture of 4584 specimens in 2001 (estimated CPUE of 0.55 specimens per 100 nets) by the deep-water gill net fishery of southern Brazil. The geographic distribution of the species ranges from Rio Grande do Sul up north to at least Rio de Janeiro. A recent taxonomic review of the *S. haeckelii-besnardi* complex [89] confirms that *S. besnardi* Springer and Sadowsky 1970 is a junior synonym of *S. haeckelii* with a grade on the color pattern [90, 91] (**Figure 4**). A new species (*S. ugoi*) was described on the northeast slope based on specimens with a lighter color pattern on the dorsal surface when still alive [92]. This new species is restricted to upper depths of the continental slope (100–500 m] and the TAMAR Project (Brazilian Marine Turtles Project) succeeded on its captured reproduction. One fourth and larger species is believed to occur on the south continental slope on deep waters (600–1000 m) and is previously identified here as *Scyliorhinus* sp. B.

***Squatina* spp**: Three species of angel sharks are recognized along the Brazilian coast: *S. argentina* (Marini, 1930), *S. guggenheim* Marini 1936 and *S. occulta* Vooren and Da Silva 1991 [93]. Two additional forms are known, but both need more analysis and specimens for an appropriate comparison. The first one is recurrently identified as *S. dumeril* Lesueur 1818 (here assigned as *Squatina* sp. A) [17, 18, 94] mostly due to an overall bluish-gray color when preserved, general aspect, similar sizes (970–1200 mm) and replication of superficial identifications rather than considering specific characters and a proper morphometric analysis. However, *Squatina* sp. A

is restricted to deep-waters and demands further taxonomic investigation. Both *S. argentina* and *Squatina* sp. A are commonly captured over the continental shelf break and upper continental slope (150–600 m), but only *Squatina* sp. A (**Figure 4**) seems to have larger abundances at deeper waters with captures sporadically reported off the north and northeast coasts of Brazil; probable continuous geographic distribution from Amapá to Espírito Santo (19º S) [17, 18, 37, 59, 94]. Not evaluated by the IUCN Red List, this species may be part of the deep-water bycatch fishery [48]. The fifth putative species *Squatina* sp. B was reported by Vaz and Carvalho [93] as *Squatina* sp., and according to these authors, it differs from all other species on the elevated number of vertebral centra, tooth count, color, position, and size of enlarged dermal denticles. More material and a further analysis are needed before a final position on both forms *Squatina* sp. A and *Squatina* sp. B is assumed.

### 2.3. Deep-water rays

***Gurgesiella dorsalifera*:** This small skate is commonly captured as bycatch by the southern deep-water squid trawl (**Figure 6**). The species has no economic value due to its small size and is frequently misidentified as *Psammobatis* or other juvenile rajids. Most of the specimens landed were adhered to the squids, but probably a larger proportion was discarded at sea immediately after capture. Its high endemism off southern Brazil is a matter of concern [65]. After considering the endemism and on growing fishery risk, it was listed as a vulnerable species by the IUCN Red List of Threatened Species [58, 64, 67, 95–97].

***Benthobatis kreffti***: This recently described small species of blind electric ray is reported only off south/southeastern Brazil where it is occasionally found as bycatch in the deep-water otter trawl squid fishery [25, 97, 98] (**Figure 6**). Its small size, glandular shape and absolute no economic value makes it easier to be ignored by onboard observers among the trawled squid. Due to its presumed feeding aggregation over polychaete-rich sediments, one single hour trawl may capture a large number that perfectly fits in a small plastic basket. Commercial and scientific cruises were able to capture more than 150 specimens in a couple of trawls, which added to the low fecundity of the species (maximum of 2 embryos per gestation period) [98] makes it a vulnerable animal to any fishery effort.

***Dipturus* spp**: Four species of *Dipturus* are reported for the Brazilian continental slope and tree species are under analysis: *D. teevani* (Bigelow and Schroeder, 1951), *D. leptocaudus* Krefft and Stehmann 1974, *D. mennii* Gomes and Paragó 2001, *D. bullisi* (Bigelow and Schroeder, 1962), *Dipturus* cf. *garricki* (Bigelow and Schroeder, 1958) and *Dipturus* sp. A and *Dipturus* sp. B [17, 19, 26, 36, 64, 99, 100]. However, a taxonomic review of this genus is strongly necessary since several misidentifications and descriptions seem to have occurred. The genus *Dipturus* comprises a complex and morphologically conservative group with diagnostic characters that change during the animal growth and maturity [101]. The ontogenetic morphological variation makes it difficult for the specific identification of neonates and juveniles by onboard observers and specimens are frequently misidentified as *R. agassizi* or *Sympterygia acuta* Garman 1877. *Dipturus trachydermus* Krefft and Stehmann 1974 is regularly recorded, but its occurrence needs confirmation [15, 102]. Large specimens are commercialized, but a great number of neonates and juveniles are discarded as bycatch (**Figure 6**). Newly hatched

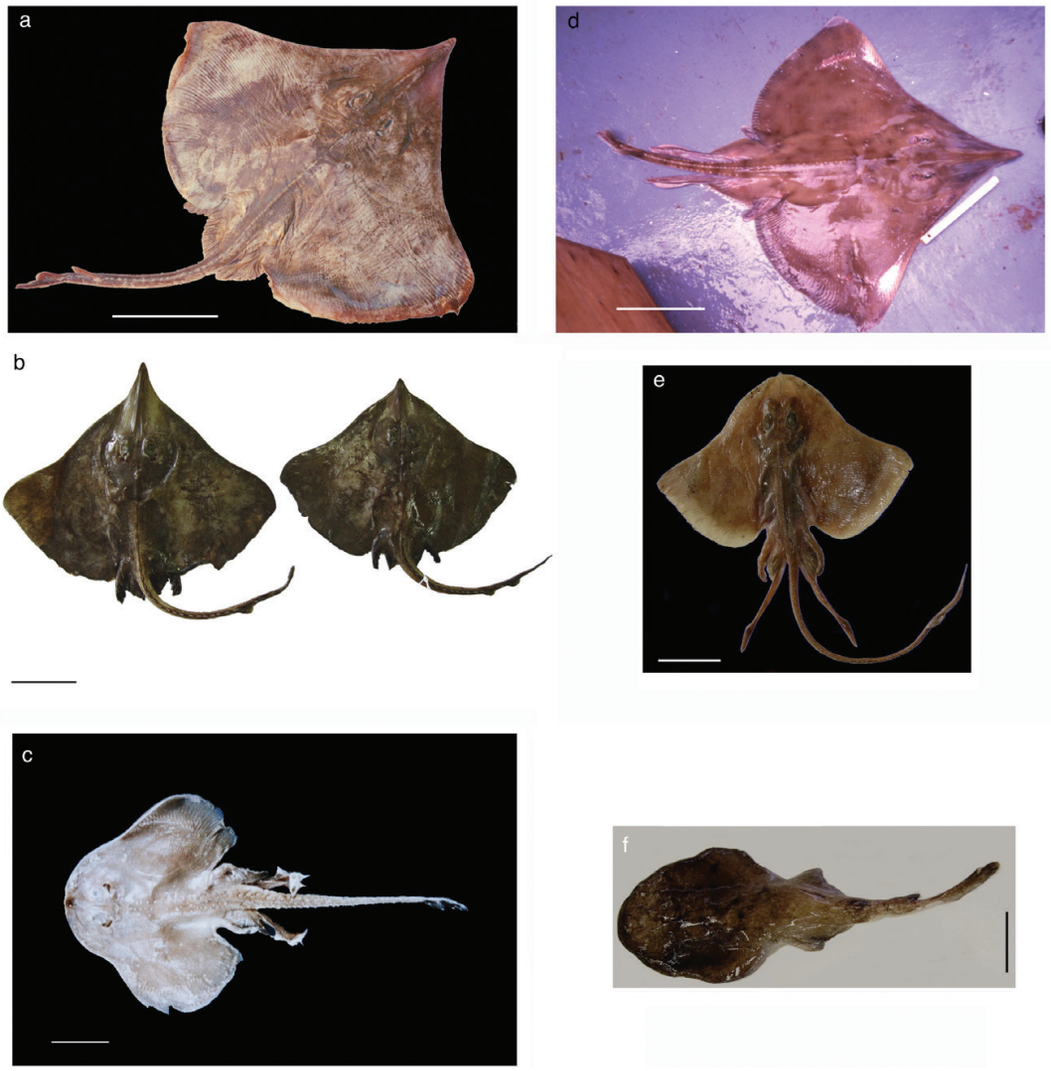


**Figure 6.** Deep-water rays and respective scale references: (a) *Dipturus mennii*, 150 mm; (b) *Dipturus* spp. neonates, 20 mm; (c) *Breviraja spinosa*, 50 mm; (d) *Dipturus* sp. B, 300 mm; (e) *Gurgesiella dorsalifera*, 30 mm; (f) *Benthobatis kreffti*, 25 mm.

specimens of *Dipturus* spp. with internal yolk reserves were captured by the deep-water otter trawl squid fishery in late winter (August–September) off southern Brazil, which brings concern about the future of these populations. The gill net monkfish fishery at the same area also captured mature specimens of *Dipturus* spp. (*D. trachydermus* and *D. mennii*) and these rays were the most abundant elasmobranch bycatch species with a total annual capture of 23,954 specimens and a CPUE of 2.89 ind./100 nets [15]. Visintin and Perez [102] still identify *Dipturus* as an extremely vulnerable group of species to the gill net fishery based on productivity-susceptibility analysis (PSA).

***Tetronarce puelcha* Lahille 1928**: The Argentine torpedo ray (*Tetronarce puelcha*), supposedly rare and never abundant in scientific and commercial captures off Brazil, Uruguay, and Argentina [103–105], was the third most abundant bycatch species captured by the deep-water gill net fishery off southern Brazil (estimated catch of 10,391 specimens captured in 2001 based on an estimated CPUE and *Tetronarce*/monkfish ratio) [15]. These captures corroborate

the hypothesis that *T. puelcha* is a member of the deep-water chondrofauna instead of a neritic species [106]. The northern Atlantic torpedo ray (*T. nobiliana*) was reported at deep-waters off the states of Amapá and Pará by scientific surveys of the REVIZEE program (otter trawl), and states of São Paulo and Rio de Janeiro [58], but due to the singularity of these records and lack of preserved specimens, this identification was not herein considered definitive.

Other rare deep-water species were recorded along the Brazilian coast, but most of them are known by single records or sporadic captures, e.g., *S. antarcticus* Whitley 1939, *H. griseus, B. spinosa, B. nigriventralis* McEachran and Matheson 1995, *D. leptocaudus, D. clarkii* (Bigelow and Schroeder 1958), *Malacoraja obscura* Carvalho, Gomes and Gadig 2005, *Diplobatis pictus* Palmer 1950 and *C. rugosa* Bigelow and Schroeder 1958 [15, 30, 36, 37, 58, 61, 75, 85, 107–110]. These species probably are distributed in deeper waters and are currently inaccessible to the Brazilian deep-water fishery. However, due to the large discard of unknown or unwanted small species in these fisheries, an accurate estimation of their contribution is presently speculative.

### 2.4. Chimaeras

Chimaeriforms (Holocephali: Chimaeriformes) are known in Brazil as "quimeras" and this designation includes rabbit fish, elephant fish, longnose chimaera, and all other species of this group. Four recognized species, one putative species and one unidentified species are recorded as follows: *Callorhinchus callorynchus* (Linnaeus, 1758), *Hydrolagus alberti* (Bigelow and Schroeder, 1951), *Hydrolagus matallanasi* (Soto and Vooren, 2004), *Harriotta raleighana* (Goode and Bean, 1895), *Hydrolagus* cf. *mirabilis* (Collett, 1904) and *Rhinochimaera* sp. The American Elephantfish *C. callorynchus* was the first chimaera identified and included in Figueiredo's [105] catalog of species of the state of São Paulo. This species is occasionally recorded along the continental shelf during winter months from the states of Rio Grande do Sul to São Paulo always in small numbers and captured by otter trawl or gill net. All other records are typical deep-water species, but only *H. matallanasi* [29] is frequently captured and reported on REVIZEE reports [52, 97], and bycatch monitoring programs [15, 58] (**Figure 7**).


**Figure 7.** Specimens of *H. matallanasi* captured by commercial fleet on the continental slope of Santa Catarina.

All other records are based on single or restricted captures [36, 111]. The lack of information on the group brings concern on its sustainability under a fishing pressure where it composes the bycatch.

## 3. Discussion

The concept of bycatch is somewhat controversial (see [112] for a review) and intangible for deep-water fisheries as captures may vary drastically (spasmodically) from different fishery grounds, over time and in percentage of species composition [4, 7]. In addition, market interests frequently make fishing effort to shift quickly from one species to another of previously low economic value or even completely ignored. An appropriate approach to the bycatch problem must meet the fisheries' management needs providing means for a realistic evaluation of the fishery impact on at least all populations of captured species when indirect effects of the fishery cannot be estimated. This means a specific identification of all capture including discarded and landed species [77, 78, 113] in order to provide managers with reliable information for a complete assessment. This requires well trained onboard observers and a complete capture description, not only the economically relevant portion. These observers have the tendency to give more attention to abundant, larger, and well known species, ignoring small unfamiliar creatures with occasional occurrences. However, this part of the capture is equally susceptible to easy overfishing as they are under the very same extreme environmental and ecological constrains of the deep-water habitats ([114, 115] for a review). Hence, catch levels of target species should be estimated based on the most fragile population compounding the capture—the weak link of the chain—regardless of it being a target or bycatch species. Generic categorizations should be avoided [10, 78] and a complete field guide of all captured species with an identification key would be expected to be published and available for the onboard observers as soon as the first cruises are monitored. Those species without a proper description should be treated at the species level as A, B, C, and so on (*Squalus* sp. A, e.g., [116]), and new records saved on board for posterior laboratorial identification by taxonomists [58].

The monkfish fishery case off southern Brazil is a perfect example of an ongoing well reported and studied deep-water fishery [4, 8, 15, 102, 117, 118]. However, unfortunately the IBAMA did not require any species-catch limit (quota) permission or established a precautionary approach prior to its development [4, 8]. All actions related to the management of the fishery came considerably after the catch/landing have already started and signed for a near future effort increase [118]. These actions aimed to collect fishery and biological information in order to elaborate a management plan for the monkfish fishery [8] and to avoid conflicts with the national fleet. According to Perez et al. [118], a total biomass reduction of 16 to 60% (more realistic) occurred in the main fishing grounds in 1 year (2001). As a result, Perez et al. [8] proposed a series of management actions to immediately reduce fish mortality to precautionary levels and a total allowable catch of 2500 mt. However, all management actions were developed based solely on the catch levels and population dynamics of the monkfish, not considering the biological characteristics or catch levels of the bycatch species, especially those of elasmobranchs. Since deep-water elasmobranchs seem to present an extreme

k-strategy and high extinction risk [16, 46] and may reach longevities of 70 years and age of first maturity of 44 years ($Age_{50}/Age_{max}$ = 0.62) (*Centrophorus squamosus* (Bonnaterre, 1788), [116, 119]), it is reasonable to assume that elasmobranchs are one of "the weak links of the chain" in deep-water fisheries and any management action must consider their most fragility to fishery effort. Otherwise, some bycatch deep-water elasmobranchs are under the risk of unnoticed population collapses or even local extinctions [120, 121] before target species presents any sign of exhaustion.

The Brazilian deep-water elasmobranch diversity is poorly known and the recent increase in species records and descriptions are evidences of a possible unevaluated richness along the continental slope [17, 31, 35, 36, 75]. Large species such as *M. owstoni, P. microdon, S. antarcticus*, and *C. granulosus* were only reported when scientific efforts in search of deep-water resources were recently developed (PROARRASTO and REVIZEE programs) [27, 37, 38, 61, 83]. Therefore, if a larger effort targeting deep-water elasmobranchs is performed, it would probably change the beliefs about the rarity of these animals [31, 39]. The number of reported species drastically increased from 119 to 176 along the past decade (**Figure 1**), which corresponds to a total number increase of 36%, or 63% in numeric terms of skates and rays and 16% of sharks [17, 18, 36]. This recent biological diversity boom is certainly related to the REVIZEE scientific surveys in the recent past (1996–2007) and its ongoing influence, which resulted in the most extensive effort in order to evaluate possible promising marine fishery resources in Brazil [52, 75, 122]. However, even these scientific surveys need to be properly designed to catch and better evaluate the elasmobranch biodiversity. The restricted size and operational capability of most Brazilian research vessels usually demand a small and multitasked scientific crew, able to catch and process a wide range of organisms from cephalopods to elasmobranchs, and from physics oceanographic data collection to plankton net sets. This, allied to taxonomic identification problems, lack of information on the rarity records of some species, large size of sharks and onboard deterioration due to poor ice conditioning may be responsible for previously identified problems such as onboard discards, inappropriate deposition of rare specimens in institutions without proper scientific report and biological information loss [17, 37, 61].

Deep-water species are commonly treated as the last possible fishery resources—the dead end of fisheries—with unexpected sustainability and intrinsic need of a precautionary approach and last refuge for coastal species [10, 16]. Gordon [7, 78] proposed principles and actions based on the North Atlantic deep-water fishery experience in order to create means for a possible fishery management. Perez et al. [8, 118], Perez and Wahrlich [15], and Visintin and Perez [102] have proposed a series of management actions toward the monkfish fishery off southern Brazil. These proposals are related mainly to fishery area restrictions or closures, bycatch reduction and fleet-effort control. Some additional aspects are proposed below considering species diversity in the management of deep-water fisheries based on all results herein discussed:

1. Specific bycatch identification is primordial for any management program. The use of fish categories should be completely banned in deep-water fisheries.

2. All catch must be monitored onboard, especially discarding bycatch of small species, which may have an extreme k-strategy like large species but are frequently captured in large numbers without calling attention to its population decline. The same principle is applicable to discarded or retained rare species, for which the point of economic extinction—death is inevitable for discarded or retained species—may be closer to the point of biological extinction because it is still economical to continue capturing rare bycatch species as long as the target species is still viable [123]. Therefore, the population size at which economic extinction occurs will move down closer to biological extinction than in the case of target species [121].
3. Onboard observers programs must be developed and/or improved in a larger proportion of the deep-water fleet along with means for reliable species identification (species catalogues, training, methodology, and scientific personnel). Scientific surveys are necessary in order to compare catch efficiency between different fishing gears and revision of methodologies and taxonomic approach (identification guides) of the onboard observers program.
4. Since the great majority of deep-water species are extreme k-strategists [116], fisheries management measures should be based on the most fragile (weak links), endemic, or most vulnerable species of the catch.
5. Fishing gears should be evaluated in selectivity terms and specific composition of the catch, in particular fishing grounds due to the contagious distribution of some deep-water species. Species richness and relative abundances may vary significantly as a direct interaction between benthic species and the sea floor type.
6. The assumption of the precautionary principle in fisheries requires a complete effort and fleet control, which means a restricted and monitored number of boats permitted to fish deep-water resources in specific areas and fishing grounds. Deep-water fisheries should not receive subsidies allowing fast growth without a proper scientific side-by-side development.
7. Deep-water resources should not be seen as economical alternatives to continental shelf collapsed resources; instead, the deep-water habitats should be considered as the new candidates for conservation [10]. The "gold rush" behavior must be controlled in order to successfully implement the precautionary principle (catch rates, effort control, monitoring and onboard programs, fishing areas, and others).
8. The proportion of endemic species in the catch should be considered when deep-water fisheries are being evaluated for implementation or management. Deep-water sharks and rays are often assumed as wide geographical range species, but when a relevant proportion (>5%) of deep-water endemic species makes part of the elasmobranch assemblage—catch, an additional precautionary reinforcement should be added.

These proposals and arguments for the Brazilian deep-water fishery management were not finally stressed and as new regions are considered to deep-water longline, trawl or gillnetting, particular and occasional needs will ask different approaches and restrictions. How hard the species diversity component will push on these management decisions is our deepest concern.

## Acknowledgements

The authors would like to express their gratitude to the REVIZEE Program, Scores North, Northeast and South; DIMAR and LOP laboratories, students and researchers at the UFRPE; and Drs. Carolus Maria Vooren and Miguel Petrere Júnior for their guidance and help. The senior author was a REVIZEE and PhD granted from CNPq and CAPES Brazilian agencies.

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