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Identification and Trends in Deepwater Sharks (DWS-2023-02)

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Abstract

This report shares the results from the project, Identification and Trends in Deepwater Sharks (DWS-2023-02). The overall goal of the project was to provide information and tools that contribute to the conservation and management of deep-water living resources in the Southern Indian Ocean. The project investigated the chondrichthyan species composition and capture rates aboard the FV Will Watch in 2024 and compared the data to data collected aboard the vessel in 2012 and 2014. Samples and data for future studies were collected and a fast and intuitive shark identification guide was developed. New innovative species identification keys were developed, tested at sea, and users were interviewed for feedback.

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Recommendations

- Continue chondrichthyan data collection to document trends over time and continue to develop a knowledge base of Indian Ocean chondrichthyan diversity and life history.
- Develop data collection tools, protocols, and data plans to study fishing impacts on chondrichthyans
- Continue voluntary collaboration with the authors to document chondrichthyan species.

1. Introduction

Deepwater chondrichthyans are understudied but widely accepted to have slow growth, late maturity, low fecundity, and low reproductive rates. Deepwater chondrichthyans are susceptible to anthropogenetic pressures and are vital keystone predators in nearly every environment they inhabit. They are often taken as accidental bycatch in commercial fishing operations.

Deepwater chondrichthyans in the Southern Indian Ocean, like in most areas, are understudied. Data needs include accurate documentation of the number of species being exploited and basic life history information to inform policy decisions concerning the vulnerability of these species to fishing pressure. To address these data deficiencies, a 76-day survey of chondrichthyans taken as bycatch was conducted aboard the F.T. *Will Watch* from 26 August to 9 November 2024. The fishing vessel deployed 350 tows undertaken at 21 stations between 365 m and 1400 m depth along the Southwest Indian Ocean Ridge and the Madagascar Ridge in a remote region of the SWIO described 30°—39.5°S; 41.5°—55.5°E (Figure 1). This current project expanded the catalogue of species present in the area and supplemented life history data for many of these poorly known species. This project also explored shark identification methods and user's success rates as part of a larger project under the Food and Agriculture Organization of the United Nation's Deep-Sea Fisheries Project. The results of this survey were compared to results from 2012 and 2014 baseline surveys conducted onboard the F.T *Will Watch* and serve as a decadal comparison of biodiversity and species abundance.

2. Funding Sources and Support

This project was accomplished with the joint support of the FAO/GEF Deepsea Shark Project and the Southern Indian Ocean Fisheries Agreement (SIOFA). VIMS provided salary and logistical support and provided matching funds in the form of overhead waivers.

Logistical support was offered by the Southern Indian Oceans Deepsea Fishers Association (SIODFA) and by United Fame Investments (UFI), a subsidiary of Sealord Group, Nelson, New Zealand. This project's unique access to the Indian Ocean deep-sea fishery and the subsequent decadal comparison was made possible by generous accommodation of the F.T. *Will Watch*, operated by UFI and flagged in the Cook Islands.

The financial and logistical support for specimen transport was from the Smithsonian Institution in Washington, DC, and the Schultz Fund.

F/V *Will Watch*, Sealord/United Fame Investments kindly provided living and working accommodations and allowed the deployment of specialized equipment as allowed by fishing. The project activities occurred during the F/V *Will Watch*'s August—November 2024 routine fishing trip.

3. Methods

<u>Fishing Vessel Operations and Fishing Effort.</u> The F.T. *Will Watch* is a 75-meter factory trawler and a 24/7 catcher/processor. She houses a crew of ~46 and has 100% observer coverage. The F.T. *Will Watch* is flagged in the Cook Islands and berths in Port Louis, Mauritius. The vessel deploys otter trawls using either bottom gear roller-equipped bottom trawls with a 15 m mouth width, 50 m wingspan, and 5 m height or mid-water trawls towed approximately 2 m off slope surfaces with an 80-100 m wingspan and a 35 m height. Tows are ~2 kt and downward along the slopes of seamounts at an initial a minimum starting depth of ~200 m and a maximum ending depth of 1400 m.

During 76 days at sea from 26 August to 9 November 2024, the fishing vessel deployed 350 tows undertaken at 21 stations between 365 m and 1400 m depth along the Southwest Indian Ocean Ridge and the Madagascar Ridge in a remote region of the SWIO described 30°—39.5°S; 41.5°—55.5°E (Figure 1). Of these 350 tows, 28 were benthopelagic (BT 3A2) and 322 were demersal trawls

(MW Trawl 111 = 48, MW Trawl 153 = 274). The vessel mainly targeted Alfonsino but occasionally targeted Orange Roughy.

Specimen Collection. Following net retrieval, bycatch was sorted and processed in the ship's factory. A suite of natural history and life history data (species, sex, length, maturity, reproduction, etc.) was collected from chondrichthyans caught as accidental bycatch by the F.T. *Will Watch* during regular fishing operations. A census of species and sex data was taken to ensure that specimens were not collected in a biased manner, which could affect estimates. All chondrichthyans encountered were examined, and the crew saved all chondrichthyan specimens and uncommon bony fishes during the researcher's sleeping hours. The tow number was recorded, and trawl information was supplied by Sealord and United Fame Investments.

During the trip, 754 chondrichthyans were encountered. All chondrichthyans were identified to species or to the lowest taxonomic level that could be confidently achieved, with sex and length (total length and precaudal length) recorded for each specimen (Table 1). Maturity stage ranking and measurements of organs related to reproduction were recorded for all male (external evaluation of claspers) and discarded female (internal evaluation of oviducal glands) specimens such that the integrity of taxonomically important specimens was preserved following Clerkin and Ebert (2015) and Mostarda et al. (2016). Taxonomically important specimens included a large mature goblin shark (*Mitsukurina owstonii*), a large Deepwater Stingray (*Plesiobatis* cf *daviesi*), lantern sharks (*Etmopterus* sp), and demon catsharks (*Apristurus* sp) believed new species.

In total, 1152 tissue samples were collected for DNA barcoding and future studies of genetic stock structure. This included samples from 424 chondrichthyans, 629 bony fishes, and 99 invertebrate species. Approximately 200 whole chondrichthyan specimens and samples were collected from 192 additional specimens for age and growth studies, including vertebrae and spine samples. Stomach contents for diet studies, spiral valves for digestion studies, oviducal glands for sperm storage studies, and liver samples for studies of chondrichthyan liver used in products were also collected from these 192 specimens.

Of the 629 bony fish tissue samples, 259 were from non-target species collected for taxonomic studies, and 370 (345 Alfonsino and 25 Orange Roughy) were from target species collected for future population genetic studies. The tissue samples collected for population genetic studies have basic information (sex, length, maturity) associated with them and include the location information (geographic location, depth, etc.) provided by the ship.

Other specimen collections included ~40 cephalopods and ~30 other invertebrates (isopods, shrimps, brittle stars, etc.). Approximately 40 internal and external parasites were collected from chondrichthyans, bony fishes, squids, and crustaceans.

Approximately 20 eDNA samples paired with a CTD profile were taken using an experimental passive eDNA sampler attached to the kite and towed in front of the mid-water nets. The ship fished between a minimum starting depth of 365 and a maximum ending depth of 1400 m. eDNA filters were frozen for future studies.

Photographs were taken for illustrative use in the digital smart key following Shotton and Clerkin (2020), and a large collection of photographs was taken to start a library of images for a species identification AI model.

While at sea, different types of chondrichthyan identification keys were trialled and, when possible, refined. The times to identification and identification success rates of users were recorded, and interviews about the keys, format, and identification were conducted.

All animals involved in this study were sampled in accordance with Institutional Animal Care and Use Committee (IACUC) protocol #17135, and interviews with the observer, crew, and vessel master were conducted under Protection of Human Subjects Committee (PHSC) protocol PHSC-2024-07-23-17135. Voucher specimens were collected and stored at IBL in Port Luis, Mauritius. Specimens will be shipped to the Smithsonian Museum of Natural History (USNM) in Washington, DC, USA.

Biological Data. The total length, sex, and maturity status were recorded for each specimen captured; maturity status assessment is detailed below. Standard measurements for sharks followed Mostarda et al. (2016). Total length (L_T) was recorded as the distance between the snout tip and the point on the horizontal axis intersecting a perpendicular, vertical line drawn down from the distal-posterior most point of the caudal lobe. The precaudal length (PCL) was defined as the distance from the snout tip to the dorsal insertion of the caudal fin. All chimaerid species have a caudal fin that slowly tapers off into a long, whip-like filament (Didier *et al.*, 2012). This distal extension of the caudal fin is often broken or absent, and the filament is homogenous in form, so it is never possible to confidently determine whether the caudal fin is completely intact. Total length measurements are, therefore, prone to error due to damage in chimaerids, and reproductive and maturity parameters are best expressed in terms body length (BDL): the distance from dorsal edge of gill the opening to the origin of the dorsal margin of the caudal fin (Inada and Garrick, 1979; Compagno *et al.*, 1990; Hardy and Stehmann, 1990).

Maturity Determination. Shark maturity was assessed by external visual inspection of claspers in males and internal inspection of reproductive organs in females (Figure 2) following Mostarda et al. (2016) and Clerkin (2017). Males were considered mature when the claspers were elongated, extended beyond the posterior free margin of the pelvic fins, were firm, and had their terminal cartilage elements calcified (Figure 2-a). Adolescent males had elongated claspers surpassing the free rear tips of the pelvic fins, but claspers were flexible and lacked calcification. Juvenile males had short, flexible claspers not reaching past the posterior margin of the pelvic fins. Inner clasper length was measured from the apex of the cloaca to the distal tip of the clasper, and the ratio of clasper length to L_T (thus normalizing clasper length) was plotted against L_T. An abrupt change in clasper length to L_T ratio has been used previously to indicate maturity. Males were not examined internally for maturity.

Females were considered mature when large yolky oocytes were present in the ovaries, and the oviducal gland was well developed and distinctly differentiated from a pendulous uterus (Mostarda et al., 2016; Clerkin, 2017). The uterus was enlarged with pendulously posterior portions hanging free from the body cavity (Figure 2-b). Adolescent females had small ovaries with some differentiation but had less developed, smaller oocytes lacking a defined yellow yoke. They also had oviducal glands that were underdeveloped along a thin, constricted uterus closely attached to the body. Juvenile females lacked differentiation of oocytes, and the oviducal gland was not differentiated from the thin uterus. Any individual (male or female) with a partially healed umbilical scar was considered a neonate (Carlson, 1999).

Chimaeridae maturity was assessed by external visual inspection of frontal tenaculum, prepelvic tenacula, and claspers in males, and external inspection of postanal pad and oviduct opening in females following Clerkin (2017) (Figure 3). Males were considered mature when secondary sexual characters were developed, with frontal tenaculum fully erupted and bearing thorn-like denticles, prepelvic tenacula able to articulate forward out of pockets, and claspers elongated, stiff and calcified with distal portions ending in fleshy tissue covered by a fine shagreen of denticles (Figure 3-a). Adolescent males were developing, with frontal tenaculum in the process of erupting from head, pre pelvic tenacula developing in pockets, claspers beginning to elongate, but still flexible and lacking calcification. Juvenile males were undeveloped with frontal tenaculum not erupted on the head but often marked with a white outline, prepelvic tenacula small, undeveloped, and not articulating forward out of pockets, and claspers present but very small and flexible. Total clasper length was measured from the apex of the cloaca to the distal tip of the clasper and plotted as a ratio of BDL. An abrupt change in the clasper length to BDL ratio indicated maturity (Barnett *et al.*, 2009).

Female chimaerids were considered mature when a large swollen postanal pad was well defined from tail musculature, and oviduct openings were large and dilated, often swollen and textured with papule (Figure 3-b). Adolescent females had less developed postanal pads, differentiable from tail but not yet well defined, and oviduct opening small or starting to dilate, but not swollen or textured. Juvenile females with postanal pad undeveloped, sometimes darker in color but not swelling to the point of being differentiable from the tail, and the oviduct opening not dilated, without papule, and appearing as deep dimples posterior to vent. The height and length of the postanal pad were recorded, and the ratio of the postanal pad to BDL was plotted against BDL. An abrupt change in the postanal pad height and length to BDL ratio indicated maturity (Clerkin, 2017).

Analysis. To illustrate size distributions for each species, length frequencies for males and females were plotted by. The overall proportions of each sex, as well as sex ratios of adults and sub-adults, were analyzed using a χ^2 goodness of fit test to determine whether the observed ratios significantly deviated from unity (Zar, 1996). Results are presented as a ratio of females to males (F:M, Table 2). The theoretical lengths at which 50% of male and 50% of female specimens were mature (L_{T50}) was estimated for both sexes of each species using a logistic regression (Roa *et al.*, 1999; Mollet *et al.*, 2000; Neer & Cailliet 2001) (Table 1).

Distribution. A total of 350 tows were performed by the vessel. The trawl type greatly influenced the number of chondrichthyan individuals and species caught, so chondrichthyan catch was examined by gear type (bottom trawl and mid-water trawl) as well as major geographical feature (Walters Shoal and the Southwest Indian Ridge).

4. Results Life History – Species Accounts

Centrophoridae

Centrophorus granulosus (Bloch & Schneider, 1801), Gulper shark. In all, five *C. granulosus* (two females and three males) were collected with an overall sex ratio of 1:1.5 (p-value>0.05, Table 2), but the sample size was too small to accurately determine if the sex ratio differed significantly from 1:1. The 34 samples (21 females and 13 males) collected during the 2012 and 2014 trips had a sex ratio of 1:0.6, which was also significantly different from the expected 1:1 ratio (p-value<0.05). Males ranged from 110.7 to 117.1 cm L_T (compared to 55 to 126.3 cm L_T). Females ranged from 117.1 to 1530 cm L_T (compared to 113.8 to 157 cm L_T from previous trips) (Figure 4)(Table 1). The geographic distribution was similar to previous surveys (Figure 6) and male and female specimens were taken in bottom trawls at both Walters Shoal and the Southwest Indian Ridge. When normalized by the number of tows, the 2024 survey had 0.143 per tow, 0.009 per mid-water tow, and 0.071 per bottom tow compared to 2012 which had 28 total, 0.08 per tow, 0.012 per mid-water tow, and 0.857 per bottom tow, and 2014 which had 6 total, 0.017 per tow, 0.003 per mid water, and 0.178 per bottom tow (Table 3).

Centrophorus squamosus (Bonnaterre, 1788), Leftscale Gulper Shark. A total of six *C. squamosus* (one female, and five males) were examined with a sex ratio of 1:5. The sample size was too small to a determine if the sex ratio differed significantly from 1:1. Previous surveys yielded 19 *C. squamosus* (four females and 15 males) with a similar sex ratio (1:3.8), which was significantly different from 1:1 (p-value<0.05). When normalized by fishing effort and gear type 2024 catches were similar to catches in 2012 and 2014 (Table 3).

Males ranged from 97.3 to 110.7 cm (compared to the length range of 96.6 cm L_T to 130 cm L_T, from previous surveys) (Figure 7). The single female encountered was 114.1 cm L_T, within the range of 106 cm L_T to 126 cm L_T, previously observed. All *C. squamosus* were captured in mid-water trawls. The female was encountered at Walters Shoal while the males were collected on the Southwestern Indian Ocean Ridge (Figure 8).

Deania calceus (Lowe, 1839), Birdbeak Dogfish. In all, 37 *D. calcea* (26 females and 11 males) were collected with an overall sex ratio of 1:0.4 (p-value<0.05). This is consistent with the ratio of 1:0.4 (p-value>0.05) based on data from the 42 *D. calcea* (30 females and 12 males) collected during the 2012 and 2014 surveys. Encounters from the 2024 trip were similar to previous trips when normalized by tow (Table 3). *Deania calceus* was taken in mid-water and bottom trawls from Walters Shoal and the Southwest Indian Ridge (Figure 9). Males ranged from 81.6 to 96.1 cm L_T (compared to 82.0 to 95.5 cm L_T from previous surveys) and females ranged from 49.9 to 121.4 cm L_T (compared to 86 to 116 cm L_T) with nine mature, the smallest of which measured 87.9 cm L_T (75.8% L_{Tmax})(Figures 10 and 11), and the largest immature measured 110 cm L_T. Oviducal gland width increased between 95 cm L_T and 98 cm L_T, with L_{T50} estimated to be 106.3 cm L_T.

Deania hystricosa (Garman, 1906), Rough Longnose Dogfish. A total of nine *D. hystricosa* (six females and three males) were landed from a single site on Walters Shoal (Figure 12), with an overall sex ratio of 1:0.5, but these results were not significantly different than the expected 1:1 ratio (p-value>0.05). Larger sample sizes are needed for accurate estimates. Males ranged from 74.7 to 867 cm $L_{T,}$ and females ranged from 96.0 to 113.2 cm L_T (Figure 13). *Deania hystricosa* was not reported from the 2012 or 2014 trips. This is likely due to changes in species discrimination within this genus, and the species should be genetically confirmed.

Deania profundorum (Smith & Radcliffe, 1912), Arrowhead Dogfish. Collectively, 46 *D. profundorum* (32 females and 14 males) were encountered with an overall sex ratio of 1:0.4, significantly favouring females (p-value<0.05). This is consistent with the results of the previous trips, which encountered 38 *D. profundorum* (32 females and six males) with a sex ratio of 1:0.2, significantly favouring females (p-value<0.05).

Males ranged from 41.6 to 71.5 cm L_T, (compared to 68.5 to 73 cm L_T), and females ranged from 55.2 cm to 97.0 cm L_T (smaller than the previously calculated range of 79 to 119.4 cm L_T) (Figures 14 and 15). Consistent with the findings of earlier surveys, all *Deania profundorum* were taken from mid-water trawls along Walters Shoal (Figure 16).

Overall, the number of chondrichthyans encountered per tow increased slightly in 2024 compared to previous surveys, but whether this increase is significant needs to be further evaluated.

Etmopteridae

Etmopterus alphus, Ebert, Straube, Leslie, and Weigman, 2016, White Cheek Lanternshark. A single female *E. alphus* was collected (compared to the six *E. alphus*—five females and one male—from previous trips). The female was 43.6 cm L_T and was taken with midwater gear at Walters Shoal (Figure 17). In previous surveys *E. alphus* was encountered at both Walters Shoal and the Southwest Indian Ocean Ridge (Figure 18).

Etmopterus bigelowi, Shirai & Tachikawa, 1993, Blurred Smooth Lantern Shark. A single male (315 cm L_T) and female (508 cm L_T) were collected from Walters Shoal. The previous trips yielded a single female specimen measuring 36.3 cm L_T, also collected from Walters Shoal (Figure 19).

Etmopterus cf *compagnoi, Fricke and Koch, 1990, Brown Lanternshark.* A single female *E*. cf *compagnoi* measuring 51.2 cm L_T was collected from the northern part of Walters Shoal (Figure 20). In past surveys, five *E. compagnoi* (four females and one male) were collected, with an overall sex ratio of 1:0.3 (p-value>0.05). The sample size was too small to accurately determine if the sex ratio differed from 1:1. The male was mature at 57.4 cm L_T, while the four females ranged from 48.4 to 60.8 cm L_T and were not examined internally. Occurrence was lower in 2024, but likely due to less fishing effort within the limited geographic range of the species. This species was only encountered in the northern region of the Madagascar Ridge (Figure 18 and 20) and is potentially a new species.

Etmopterus granulosus (Günther, 1880), Southern Lanternshark. A total of 449 (223 females and 226 males) were encountered, with a sex ratio of 1:1.03, which was not significantly different from a 1:1 ratio (p-value>0.05). Males ranged from 62 to 87.9 cm $L_{T,}$ while females ranged from 75 to 85.6 cm L_T (Figure 21). During previous trips, a total of 2445 (1529 females and 916 males) were examined, with an overall sex ratio of 1:0.6, with significantly more females collected (p-value<0.05). When compared by maturity status, *E. granulosus* from the 2012 and 2014 surveys shows significantly more adult females, 1:0.6 (p-value<0.05), and more juvenile females 1:0.5 (p-value<0.05). Males ranged from 21 to 92.8 cm L_T, with 395 mature individuals (43.1% of examined) (Figure 22). Females ranged from 20.1 to 101.9 cm L_T, with 598 mature (39.1% examined) (Figure 22).

Etmopterus granulosus was the most commonly encountered and geographically widespread chondrichthyan in all three surveys. Compared to earlier surveys, the 2024 trip captured approximately half as many *E*. *granulosus* total and per fishing effort (Table 3), which could indicate a decrease in abundance or a change in fishing. Further investigation into the cause of this change is warranted. Males and females were caught along both the Walters Shoal and the Southwest Indian Ocean Ridge (Figure 23 and 24) in both mid-water and bottom trawls with a depth range of 89 to 1334 m, with no clear sexual segregation. Pregnant females were present exclusively at Southwest Indian Ocean Ridge.

Etmopterus pusillus (Lowe, 1839), Smooth Lanternshark. Six *E. pusillus,* 3 female, 3 unsexed, were encountered during this trip. The six females ranged from 45.4 to 50.4 cm L_T and were taken in mid-water tows from Walters Shoal and the Southwest Indian Ridge (Figure 25).

In the previous two trips, 13 *E. pusillus* (five females and eight males) were collected, with a sex ratio of 1:1.6, not significantly different from 1:1 (p-value>0.05). Males ranged from 40.1 to 45.5 cm L_T and were all determined to be mature. The smallest male was 88.1% L_{Tmax}. Females ranged from 41.2 to 51.6 cm L_T. Internal maturity indicators and diet were not examined. Males and females were found together and only encountered along seamounts of Walters Shoal with a depth range of 580 to 1020 m. The frequency of occurrence over the surveys appears stable but should be investigated further.

Etmopterus sculptus, Ebert, Compagno & De Vries, 2011, Sculpted Lanternshark. Four female *E. sculptus* ranging from 12.1 to 50.6 L_{Tmax} were collected by bottom trawl and midwater trawl at Walters Shoal and the Southwest Indian Ridge (Figure 26). Past surveys encountered eight *E. sculptus* (seven females and one male) with a sex ratio of 1:0.1, which was significantly different from 1:1 (p-value<0.05). Only the male was mature at 46 cm L_T. Females ranged from 41 to 55.5 cm L_T, with at least three pregnant individuals, the smallest of which measured 50.1 cm L_T (90.3% L_{Tmax}). Internal maturity indicators and diet were not examined. In past surveys this species was collected from two seamounts along the Walters Shoal between 495 and 1288 m deep (Figure 18). The frequency of *E. sculptus* was lower in 2024 than in previous years, although in 2024 this group was split into *E. sculptus* and *E.* cf *sculptus,* which could account for some of the differences.

Somniosidae

Scymnodon plunketi (Waite, 1910), Plunket's Shark. Nine *S. plunketi* (four females and five males) were encountered with a sex ratio of 1:1.3, but the limited sample didn't yield significant results. Males ranged from 807 to 1348 cm $L_{T,}$ while females ranged from 1430 to 1572 cm $L_{T.}$ Previous trips yielded more *S. plunketi*, there were 50 encounters (27 females and 23 males), with a sex ratio of 1:0.9 (p-value>0.05). Comparison based on maturity level revealed adult males did not significantly outnumber adult females (sex ratio = 1:1.6, p-value>0.05), but juvenile females were almost 3 times as abundant juvenile males, 1:0.3 (p-value<0.05). Males and females were taken from seamounts of the Southwest Indian Ocean Ridge and Walters Shoal in both mid-water and bottom trawls (Figure 27 and 28). The frequency of *S. plunketi* in the 2024 survey was comparable to previous surveys, but further analysis needed to study potential changes in abundance.

Centroscymnus coelolepis Barbosa du Bocage & de Brito Capello, 1864, Portuguese Dogfish. Four *C. coelolepis* (one female and three males) were collected with a sex ratio of 1:3, but the sample size was too small to assess whether the observed difference was significant. Males ranged from 88.6 to 94.3 cm L_T, while the only female was 96.4 cm $L_{T.}$

Previous trips encountered a higher number of *C. coelolepis* (50 total, 42 females and eight males) which was significantly different from the null hypothesis of 1:1 (p-value<0.05). Among mature individuals, females outnumbered males 1:0.3, but the comparison was not significant (p-value>0.05). A significant majority of juveniles were female (1:0.15, p-value<0.05).

Males ranged from 81 to 95.6 cm L_T, with three mature individuals encountered (37.8% of males). Clasper size increased between 89.5 and 90.5 cm L_T. The smallest mature male measured 90.2 cm L_T (94.4% L_{Tmax}), and the largest immature male was 95 cm L_T, with L_{T50} estimated at 92.6 cm L_T. Females ranged from 69.5 to 123.3 cm L_T, and 9 were mature (21.4% of females). Oviducal gland width spiked between 102 and 104 cm L_T. The smallest mature female measured 105 cm L_T, the largest immature reached 111 cm L_T, and L_{T50} was estimated at 105.9 cm L_T. There were many fewer *C. coelolepis* in the 2024 survey than in previous surveys, both in terms of total collected and per fishing effort. Changes in fishing or potential seasonality should be assessed.

Centroscymnus owstonii, Garman, 1906, Roughskin Dogfish. No C. owstonii were encountered in the 2024 survey. During the two previous trips in 2012 and 2014, a combined total of 44 *C. owstonii* (31 females and 13 males) were encountered, with a sex ratio of 1:0.4 (p-value<0.05), indicating significantly more females. Examination by maturity stage revealed adult females were more abundant than adult males 1:0.4 (p-value<0.05).

Males ranged from 44.2 to 95.1 cm L_T, and 3 were mature (23.1% total). The smallest mature male measured 84.9 cm L_T, 89.3% of L_T max. Clasper length increased between 81 and 88 cm L_T, the largest immature male measured 91 cm L_T, and L_{T50} was estimated at 90 cm L_T. Females ranged from 75.6 cm to 114 cm L_T, with five mature (16.1% of encountered females). Oviducal gland width increased between 108 and 110 cm L_T. The smallest mature female measured 79.8 cm L_T and was 70% of L_{Tmax}, the largest immature female was 113 cm L_T, and L_{T50} was 99.9 cm L_T. *Centroscymnus owstonii* was found at 800 to 1400 m deep at both the Southwest Indian Ocean Ridge and Walters Shoal in between 686 and 1350 meters, with its distribution overlapping that of *C. coelolepis* (Figure 29).

*Centroselachus crepidater (Barbosa du Bocage & de Brito Capello, 1864), Longnose Velvet Dogfish.*In total, 61 *C. crepidater* (34 females and 23 males, four unsexed) were examined and had an overall sex ratio of 1:0.7, which was not significantly different than 1:1 (p-value>0.05). Males ranged from 34.9 to 887 cm L_T, and females from 89.2 to 127.1 cm L_T (Figure 30) Animals were taken by mid-water and bottom trawl from both Walters Shoal and the Southwest Indian Ridge. The previous trips examined 300 *C. crepidater* (217 females and 83 males), with an overall sex ratio of 1:0.4 (p-value<0.05).

Examination by maturity status revealed mature females outnumbered mature males by nearly threefold (1:0.4, p-value<0.05), and juvenile females significantly outnumbered juvenile males (1:0.2, p-value<0.05). Males ranged from 20.5 to 94.9 cm L_T, with 54 mature (65.1% of those encountered) (Figure 31). Clasper length increased between 60 and 63 cm L_T (Figure 31-b) with the smallest mature individual measuring 63.2 cm L_T (66.6% L_{Tmax}), the largest immature measured 66.4 cm L_T, and L_{T50} was estimated to be 60.4 cm L_T. Females ranged from 37.5 to 145.8 cm L_T, with 93 mature (42.9% of total females) (Figure 31-c). Oviducal gland width increased sharply between 73 and 75 cm L_T (Figure 31-d), with the smallest mature measuring 78 cm L_T (53.5% L_{Tmax}), the largest immature 86.0 cm L_T, and L_{T50} was estimate at 88.3 cm L_T. This species was encountered less frequently in the 2024 trip in total, per tow, and in bottom tows than in previous surveys. The percent catch in midwater tows increased, although this is potentially a result of changes in fishing practices. Further study is needed. The species appears to have a wide geographical range (Figure 31).

Zameus squamulosus (Günther, 1877), Velvet Dogfish. A single male *Z. squamulosus* measuring 503 cm L_T was taken via bottom trawl on the Southwest Indian Ridge in the 2024 survey (Figure 32). In 2012, five *Z. squamulosus* (one female and four males) were encountered, but the sample size was too small to accurately determine if the sex ratio differed from 1:1 (p-value>0.05). Males ranged from 52 to 53 cm L_T, with three mature individuals. Clasper length increased between 52 and 53 cm L_T. The smallest mature male measured 52.5 cm L_T (99.1% L_{Tmax}), and the only immature male measured 52 cm L_T, and L_{T50} was estimated to occur at 52.3 cm length. The only female specimen measured 92.9 cm L_T, nearly twice the size of the largest male, and was pregnant. Oviducal gland width was 1.0 cm, and the female had three pups in the left uterus. Pups were all female, measured from 14.8 cm to 15.5 cm, and were moderately developed with a large amount of external yolk sack not yet absorbed. In 2012 this species was encountered on Walters Shoal with a depth range of 810 to 1060 m and was collected in low numbers (one or two) from different seamounts (Figure 28).

Somniosus cf rostratus, Little Sleeper Shark. No specimens were encountered during this trip. A single specimen of *S.* cf. *rostratus* was collected from previous trips. The specimen was a neonate male measuring 30.2 cm L_T, taken from the Southwest Indian Ocean Ridge between 670 and 755 m deep (Figure 28). This specimen is expected to represent a new species.

Somniosus antarcticus, Whitley 1939, Southern Sleeper Shark. A single neonate male measuring 107.0 cm L_T was collected using bottom gear off the South Indian Ocean Ridge (Figure 33). This species was found during 2024 but not in the earlier surveys.

Dalatiidae

Dalatias licha (Bonnaterre, 1788), Kitefin Shark. In total, 35 female *D. licha* ranging from 93.5 to 150.9 cm L_T (Figure 34) were collected from mid-water (n=30) and bottom trawls (n=4) along Walters Shoal and the Southwest Indian Ridge (Figure 35). In previous trips, a total of 175 *D. licha* (165 females and 10 males) were collected with a sex ratio of 1:0.1 (p-value <0.05). Comparison by maturity stage revealed females outnumbered males in the adult stage by 1:0.05 (p-value<0.05) and in the juvenile stage by 1:0.07 (p-value<0.05). Males ranged in size from 47.1 to 112 cm L_T, with four mature males (40% of males) (Figure 36).

Mitsukurinidae

Mitsukurina owstoni, Jordan, 1989, Goblin Shark. A single Goblin shark was encountered during a mid-water trawl on the Southwest Indian Ridge (Figure 37). The mature male measured 336.0 cm L_T. This was a rare sighting for this species in this region. This species was found during 2024 but was not in the earlier surveys.

Scyliorhinidae

Apristurus sinensis, Chu and Hu, 1981, South China Catshark. A total of 20 *A. sinensis* (eight females, 10 males, two unsexed) were encountered with a sex ratio of 1:1.3 (p-value>0.05). Males ranged from 59.1 cm to 75.7 cm $L_{T,}$ while females ranged from 60.5 cm to 69.6 cm L_T.

Previous surveys yielded a total of 93 total *A. sinensis* (34 females and 59 males) were encountered, with a sex ratio of 1:1.7, significantly favouring males (p-value<0.05). Males ranged from 32.2 to 102.5 cm L_T, with 39 mature (66.1% total males). Clasper length increased sharply between 55 and 60 cm L_T, with the smallest mature measuring 63.1 cm L_T (61.6% L_{Tmax}), the largest immature 66 cm L_T, and L_{T50} estimated to be 60.3 cm L_T. Females ranged from 47.7 to 109.1 cm L_T. Two female specimens were examined internally; one was immature at 74.4 cm L_T, while the other was mature at 93.9 cm L_T.

Apristurus sinensis was the most encountered catshark in the area and appears to be geographically widespread. Encounters were less frequent during the 2024 trip than previous trips, and significance testing is required. Males and females appear to share seamounts and were collected in the same tows from 800 to 1300 m deep, along both the Southwest Indian Ocean Ridge and Walters Shoal, between 89 and 1365 m deep (Figure 38 and 39).

Apristurus manocheri, Cordova and Ebert, 2020, *Manocheri Catshark.* A single specimen was taken by bottom trawl from Walters Shoal (Figure 40). This is less than the 10 (eight from 2012 and two from 2014) observed previously, though significance needs to be determined. Specimens from previous trips had a sex ratio of 1:0.6 (p-value>0.05). Males ranged from 39.7 to 55.1 cm L_T, with only the largest being mature. Females ranged from 50.2 to 52.4 cm L_T and were not examined internally.

Apristurus cf. ampliceps, Roughskin Catshark. eight A. cf. *ampliceps* were collected, six females and two unsexed. This species was less commonly encountered in 2024 than in 2012 and 2014 (Table 3). Males ranged from 59.1 to 75.7 cm L_T, while females ranged from 60.5 to 69.6 cm L_T. This species is likely a complex, with more than one species in this group, potentially invalidating comparisons. The *Apristurus* genus needs more taxonomic study.

Bythaelurus bachi, Weigmann, Ebert, Clerkin, Stehmann, and Naylor, 2016, Bach's Catshark. A total of three *B. bachi* were encountered (two females and one male), with a sex ratio of 1:0.5, but the sample size was too small to accurately determine if the sex ratio differed from 1:1 (p-value>0.05). The only male collected was mature at 65.1 cm L_T. The females were 43.1 and 45.9 cm L_T. This species was encountered at a rate that is comparable to previous trips (Table 3). *Bythaelurus bachi* was found from only three seamounts (Figure 41).

Bythaelurus naylori, Ebert and Clerkin, 2015, Dusky Snout Catshark. In all, five specimens of *B. naylori* (three females, two males) were collected from the Southwestern Indian Ridge (Figure 42) with a sex ratio of 1:0.7, but the sample size was too small to accurately determine if the sex ratio differed from 1:1 (p-value>0.05), which was also the case with previous surveys. Males ranged were 51.4 and 54.1 cm L_T, and females ranged from 57.2 to 48.7 cm L_T. While there were fewer *B. naylori* encountered in 2024 then the previous surveys, statistical testing is needed to see if this difference is significant.

Pseudotriakidae

Pseudotriakis microdon, de Brito Capello, 1868, False Catshark. A total of three *P. microdon* were encountered. All were male and ranged from 175.0 to 234.1 cm L_T. One male, measuring 190.4 cm, still had an umbilical scar. In previous surveys, 28 individuals (10 females and 18 males) were encountered with an overall sex ratio of 1:1.8 (p-value<0.05). When compared by maturity status, mature males significantly outnumbered females 1:4.5 (p-value<0.05), while immature individuals had a sex ratio of 1:1.1 (p-value>0.05).

Male *P. microdon* from previous surveys ranged from 135 to 233 cm L_T, with 9 mature (50% of encountered). Clasper length increased between 200 and 210 cm L_T. The smallest mature male measured 213 cm L_T, the largest immature male was 198.3 cm L_T (91.4% of L_{Tmax}), and L_{T50} was estimated to be 205.7 cm L_T. Females ranged from 158 to 291.2 cm L_T, with two pregnant individuals. Oviducal gland width increased between 223 and 226 cm L_T. The smallest mature female measured 267 cm L_T (91.7% L_{Tmax}), the largest immature was 220.8 cm L_T, and L_{T50} was estimated to be 243.7 cm L_T.

Mature female *P. microdon* from previous surveys had numerous (estimated several thousand) small oocytes in each ovary. Pregnant females had a single large pup per uterus. A non-term embryo measured 69.1 cm L_T, lacked a bloated stomach full of yolk, and had a very large external yolk sac connected by a short umbilical cord. The largest embryo measured 124.4 cm L_T and appeared to be full term and had fully absorbed its yolk sac.

Pseudotriakis microdon was encountered at a much lower rate than on previous trips, but this is thought to be a function of fishing effort on specific hills (Figure 43). This species appears to have a very limited distribution, but they are caught consistently during fishing on the seamounts they inhabit. It seems likely that their frequency of occurrence is more linked to fishing effort in these areas than to overall abundance.

Chimaeridae

Chimaera willwatchi, Clerkin, Ebert, and Kemper, 2017, Seafarer's Ghostshark. A total of eight *C. willwatchi* (three females and five males) were encountered along the Southwestern Indian Ridge (Figure 44) with a non-significant sex ratio of 1:1.7. Previous trips yielded a total of 52 *C. willwatchi* (35 females 17 males) with a sex ratio of 1:0.5, (p-value<0.05).

Males from the previous trips ranged from 25.2 cm BDL (47.9 LT) to 49.2 cm BDL (83.4 LT), with five mature (29.4% of encountered). Clasper length increased between 40 cm BDL and 45 cm BDL and correlated with a spike in frontal tenaculum length and bulb width. The smallest mature male measured 45.6 cm BDL (92.7% BDL_{max}), the largest immature male was 49.0 cm BDL, and L_{T50} was estimated to be 45.6 cm BDL.

Female *C. willwatchi* ranged from 11.8 cm BDL (29.0 cm L_T) to 64.5 cm BDL (90.0 cm L_T), with 7 mature (25.6% total). Females matured at a larger size than males, with the smallest mature female at 51.9 cm BDL (76.7 cm L_T), the largest immature female at 52.9 cm BDL (91.3 cm L_T), and L_{T50} estimated to be 51.4 cm BDL (87% BDL_{max}). The smallest free-swimming individual, a female 11.8 cm BDL, 25.8 cm L_T, was white with translucent regions on its abdomen, suggesting it was recently hatched and of minimum size for the species.

From the previous surveys mature *C. willwatchi* were found exclusively on three sites at the northwestern break of the Southwest Indian Ridge (Figure 45). Mature males were collected at the single farthest northwestern site along the Southwestern Indian Ridge, and mature females were found on two nearby sites to the southeast. Although sites in this region were the only areas where mature individuals were found, mature individuals were in the minority, with all maturity stages present, including a hatchling. Both sexes were found at similar depths ranging between 89 and 1365 m.

Chimaera willwatchi was the only species of *Chimaera* encountered in the region during this trip, with the less common C*himaera didierae, Clerkin, Ebert, and Kemper, 2017, Falkor Chimaera* and *Chimaera buccanigella, Clerkin, Kemper, and Ebert, 2017, Dark-mouth Chimaera* absent during this study. The *Hydrolagus* sp nov. from the area was also not observed during the 2024 survey.

Glaucostegidae

Plesiobatis cf daviesi (Wallace, 1967), Deepwater Stingray. One Plesiobatis daviesi was collected by mid-water trawl from Walters Shoal (Figure 46). This species is uncommon and was only recorded during the 2024 survey.

5. Discussion

Biodiversity

During the trip, 28 species of chondrichthyans (including three sp) from 15 genera were encountered. This is an increase from previous research in the area with 24 species encountered in 2012 and 18 (including one sp) encountered in 2014. There was overlap between the species found in the three-surveys with 36.1% (13) species found in 2012, 2014, and 2024 (Figure 47). The 2024 survey had the highest number of novel encounters, with 22.2% (8) of species not seen in the previous two trips. This was followed by the 2012 trip with 11.1% (4) then the 2014 survey with 8.3% (3) novel species. Lower biodiversity in 2014 could have to do with the relatively smaller number of sites (18) distributed in a smaller area (Figure 48) when compared to 2012 (31 sites) and 2024 (21 sites).

The SIOFA area is taxonomically under-documented, and the taxonomic uncertainty makes biodiversity more difficult to quantify. *Deana calcea* and *D. hystricosa* have overlapping taxonomic characters, and the genus is still undergoing revisions. These taxonomic revisions and reclassifications make it difficult to compare data collected at different times because what was once considered a single species might now be recognized as multiple distinct species (or vice versa). Other groups like *Etmopterus* and *Apristurus* are morphometrically conservative and are continuously accumulating additional species. These groups also undergo ontogenetic shifts and exhibit sexual dimorphism, making it hard to discern new species from variation within an under-documented species. This can lead to optimistic taxonomic inflation or convenient taxonomic lumping, which can obscure true biodiversity.

During these three surveys, eight species (*Apristurus manocheri, Bythaelurus bachi, Bythaelurus naylori, Etmopterus alphus, Etmopterus brosei, Chimaera buccanigella, Chimaera didierae, Chimaera willwatchi*) have been identified and described, with seven potential new chondrichthyan species awaiting formal description. The 2024 trip discovered species not encountered in the two previous surveys as well as species that are new to science, underscoring the importance of continued molecular and morphological-based taxonomic work in this region.

Abundance

The overall abundance of chondrichthyans was lower than in previous years, with 754 chondrichthyans encountered during 2024, 2315 in 2012, and 1377 in 2014. If normalized to the simplest catch per unit effort (CPUE) of 1 tow = 1 unit of fishing effort, chondrichthyan CPUE is 10.9 (2315 chondrichthyans /212 tows) for 2012 and 6.4 (1377 chondrichthyans /214 tows) for 2014, which is much higher than the 2.2 (754 chondrichthyans/350 tows) from 2024.

Deepwater chondrichthyans are benthic associated. If we normalize CPUE by 1 tow = 1 unit of fishing effort gear by type and assess fishing effort for bottom tows and mid-water tows separately, we get a chondrichthyan CPUE of 18.1 (bottom trawl 2012), 3.6 (mid-water 2012), 19.6 (bottom trawl 2014), 2.5 (mid-water 2014), which is more comparable to CPUEs of 16.6 (bottom trawl 2024) and 0.9 (mid-water 2024). These numbers are more comparable, but analysis is still needed to determine if these changes are statistically significant.

Fluctuations in rare species like *Zameus squamulosus*, some Chimaeriod species, *Etmopterus*, and *Apristurus* species can largely be due to chance. Taxonomic uncertainty further complicates species frequency counts. Splitting a group (example: Apristurus sp, n=20) into two species (example: Apristurus sp a, n=13 and Apristurus sp b, n=7) decreases their total compared to the case where they were lumped as a single species.

Certain species like *Pseudotriakis microdon and Etmopterus* cf *compagnoi* are caught consistently but only within relatively small geographical areas, linking their perceived abundance to how many tows are done in these areas.

Species like *Centroscymnus coelolepis*, *Etmopterus granulosus,* and *Centroselachus crepidater* appear to be caught in lower frequency than in 2012 and 2014, although significance testing is still needed. This lower frequency of occurrence could be related to changes in fishing practices over the decade (both captains from the 2012 and 2014 trips are now retired) or season and focus on different target species. Fishing has changed over the past decade, and it is hard to tell how this has impacted chondrichthyan catch rates. Worth noting, there were a large number of tows during the 2024 trip that had no sharks, as opposed to fewer sharks. This would impact catch per tow/effort, but the tows with a complete absence of chondrichthyans could reflect changes in fishing rather than decreases in chondrichthyan biomass, which assumably would result in tows with fewer chondrichthyans rather than no chondrichthyans.

While some trends seem apparent, further investigation and statistical analysis are needed. These will be undertaken with the goal of yielding more statistically conclusive statements of abundance trends.

Sex ratios

Sex Ratios. The overall sex ratio for male and female individuals were encountered was approximately 1:1, or the sample size was too small to show any skewed sex ratios. Three species were significantly skewed toward females and 12 species only one sex was encounter (Table 2). Although the results of the present study did not suggest segregation of S*. plunketi* based on the sex ratios of adults, a separation by size and sex has been reported in the literature (Compagno, 1984).

Viviparous species tended to have strongly skewed adult sex ratios (up to 19:1 in favour of females in *Dalatias licha* in the 2012 and 2014 surveys), which has been documented in the literature and is theorized to be linked to behaviour (Capapé, 2008). High numbers of mature females could indicate sexual segregation after adulthood, potentially as the result of a broader movement pattern or some form of differential habitat use among mature individuals (Grubbs, 2010). This kind of segregation in adults of a species is well documented and considered common in elasmobranchs (Springer, 1967; Yano and Tanaka, 1988).

Notably *Etmopterus granulosus* and *Centroselachus crepidater*, which had large sample sizes did not show significantly skewed sex ratios as they did during the previous surveys. Changes in sex ratios suggest migration by males and females over time. However, since conditions are relatively constant in the deep sea, reproductive cycles are usually asynchronous, without defined seasonality, and are therefore unlikely to influence segregation in this ecosystem (Wetherbee, 1996; Kyne and Simpfendorfer, 2010). Sexual segregation is likely influenced by environmental factors such as diet and differential foraging patterns that could be a function of different caloric requirements associated with each sex's role in reproduction (Grubbs, 2010).

Seasonal migration could affect sex ratios and could potentially affect the abundance, distribution, and habitat use of deepwater sharks, which might not be as aseasonal as previously believed. Alternatively, species with sexual segregation could have different sex ratios depending on fishing behaviours, which could be linked to target species behaviour, seasons, and weather. Further study of seasonal abundance would be useful.

6. Conclusion and Recommendations

The objectives of this study were to collect data and specimens to contribute to clarifying the ambiguous taxonomic status of SWIO chimaeroids and catalogue the chondrichthyan fauna along the northern section of the Madagascar Ridge, Walters Shoal, and the Southwestern Indian Ocean Ridge to provide a baseline of life history data.

The study area was speciose, with 31 species encountered during the three surveys from 14 genera, and 25 known species (and several unknown) species from the 2024 survey spanning 15 genera

(*Centrophorus, Deania, Etmopterus, Scymnodon, Centroscymnus, Centroselachus, Zameus, Somniosus, Dalatias, Mitsukurina, Apristurus, Bythaelurus, Pseudotriakis, Chimaera,* and *Plesiobatis*). Biological data was collected to compile an overview of the region's shark fauna. Although life history traits are among the most important parameters with which to evaluate species productivity (Simpfendorfer *et al.*, 2011; White and Last 2012), such data are largely absent for deep-sea sharks in the SWIO. During this study, a census of life history data was collected from chondrichthyan bycatch to provide an overview of chondrichthyans in this understudied region. The surveys spanned 46 sites and over 750 hauls to provide a rudimentary catalogue of species and baseline of population and life history information. More comprehensive studies are required to better understand the status of SWIO deep-sea sharks and improve the information available to policymakers. New species and first accounts taken during these surveys emphasize how much we have yet to discover about chondrichthyans in the deep ocean and highlight the complex variation in life histories among deep-sea chondrichthyan species. Ensuring the sustainable harvest of Indian Ocean living resources requires policy makers to have the information they need to make informed decisions. The results of this study and future work based on these surveys will contribute to the growing knowledge base essential to developing sustainable, ecosystem-based management.

7. Next steps and Potential future projects

Future projects that the SIOFA Scientific Committee might wish to consider for inclusion in its Workplan going forward:

- *Further analysis.* Data from this project will be further analyzed to quantify changes in biodiversity and abundance. This report presents the survey findings and compares them to the previous surveys. A lot of data was collected, some falling outside of the scope of the report. The researcher plans to continue with further analysis.
- *Taxonomic studies.* Specimens and genetic tissues from the 2024 survey have been collected for taxonomic research. New species descriptions and resolution of cryptic species will improve the impact of species-specific data.
- *Identification Keys.* Identification keys developed in partnership with FAO during this project could be implemented to increase taxonomic accuracy. Observations and interviews with users generated notes on what characters are most useful to non-taxonomists in identifying species. Future efforts could continue to assess which characters result in the most accurate species identifications and how users learn to identify fish, shifting the focus of these keys from taxonomy-based to user-based characters. Development of additional tools like training videos and single-page flip keys could help non-taxonomists accurately identify species. This would result in more useable observer data.
- *Deepwater chondrichthyan species catalogue and molecular barcode database*. A record of shark species encountered during the 2024 survey will be produced as a deliverable for FAO under the current funding agreement. **Potential future work**: Continued work could include a molecularly verified and vouchered catalogue of chondrichthyan species encountered during the 2024 survey of the Southern Indian Ocean and associated life history information (geographical distribution, sex ratio, length at maturity, fecundity, etc.).
- *Age and growth of deepwater sharks*. Understanding ages and growth rates of deepwater chondrichthyan species is crucial to inform fishery management and establish sustainable catch limits, especially for slow-growing species. Many deep-sea chondrichthyan species have yet to be successfully aged. This is largely due to the lack of samples available and issues inherent in aging deep-sea species. Vertebrae and spines were collected from *Centroscymnus coelolepis* and *Centrophorus granulosus* and frozen during the 2024 trip. Spines could be sectioned and aged, while vertebrae could be double stained using cobalt

nitrate and ammonium sulfide. A von Bertalanffy growth curve and/or Lester growth model could then be estimated on a species-by-species basis depending on the number of samples collected for each species. The resulting estimates could contribute to the information needed to set the total allowable catch for the deepwater shark species studied.

- *Alfonsino population genetics*. Splendid alfonsino (*Beryx splendens*) is a commercially valuable fish, but due to its slow growth and early sexual maturity, the species may be vulnerable to overfishing. There is little information about the species' population structure. An understanding of the genetic diversity and population structure is needed to maintain a sustainable fishery and understand how the SIO alfonsino stock should be managed. Alfonsino tissue samples were taken during the 2024 survey. **Potential future work**: This study would examine the genetic stock structure of alfonsino within the SIOFA fishing area. This information could then be used in recommendations for managing the fishery.
- *Deepwater shark trophic ecology.* This study would investigate the feeding ecology of three abundant but poorly known deep-sea shark species in the Southwestern Indian Ocean: *Etmopterus granulosus* (Southern Lanternshark), *Centroselachus crepidater* (Longnose Velvet Dogfish), and *Dalatias licha* (Kitefin Shark). These species are frequently caught as bycatch, yet little is known about their diet composition, resource partitioning, or how these factors differ between sexes. Stomach samples from these sharks were collected during the 2024 field trip. **Potential future work**: Stomach samples can be analysed using traditional taxonomic methods and/or batch DNA metabarcoding to identify prey items, and stable isotope analysis could be used in the analysis of food webs. The diets of the three species could be compared to determine if they compete for the same resources and how diet composition differs between males and females. The resulting information will improve our understanding of the role of these sharks in the deep-sea food web and their vulnerability to human impacts.

8. Recommendations

R1: Long-Term Monitoring

Further developing a long-term monitoring program for chondrichthyan species will provide essential data on population trends, changes in biodiversity, and the long-term impacts of fishing pressure. Regular data collection will cover different seasons and fishing methods and result in higher resolution data for conservation and management needs.

R2: Standardized Data Collection Protocols

Developing and implementing standardized data collection protocols will ensure consistency and comparability across surveys. This could include refining species identification tools, observer training regarding chondrichthyan data collection, and data reporting and sharing systems to improve data use.

R3: Continue Collaborative Research

We propose continued voluntary collaborations between the authors and vessels fishing in the SIOFA area. The fishing vessels' access to deep-sea specimens and data could greatly benefit research which in turn would provide information for policy makers and other stakeholders.

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10. Appendices

(Table 1) with sex and length (total length in mm) recorded for each specimen. M = male and F = female.

Species	**sex**	**minimum length**	**maximum length**
Apristurus ampliceps	F	452	528
Apristurus sinensis	F	605	696
Apristurus sinensis	M	591	757
Bythaelurus bachi	F	431	459
Bythaelurus bachi	M	651	651
Bythaelurus bachi	F	431	459
Bythaelurus bachi	M	651	651
Centrophorus granulosus	F	1171	1530
Centrophorus granulosus	M	1107	1171
Centrophorus squamosus	F	1241	1241
Centrophorus squamosus	M	973	1107
Centroscymnus coelolepis	F	964	964
Centroscymnus coelolepis	M	886	943
Centroselachus crepidater	F	89.2	1371
Centroselachus crepidater	M	349	887
Chimaera willwatchi	F	494	944
Chimaera willwatchi	M	552	833
Dalatias licha	F	935	1509
Deania calceus	F	499	1214
Deania calceus	M	816	961
Deania hystricosa	F	960	1132

Deania hystricosa	M	747	867
Deania profundorum	F	552	970
Deania profundorum	M	416	715
Etmopterus (cf) sculptus	F	384	545
Etmopterus alphus	F	436	436
Etmopterus bigelowi	M	315	315
Etmopterus granulosus	F	**75**	856
Etmopterus granulosus	M	62	879
Etmopterus pusillus	F	454	504
Etmopterus sculptus	F	121	506
Mitsukurina owstoni	M	3360	3360
Pseudotriakis microdon	M	1750	2341
Scymnodon plunketi	F	1430	1572
Scymnodon plunketi	M	807	1348
Somniosus antarcticus	M	1070	1070
Zameus squamulosus	M	503	503

Table 2. The overall proportions of each sex, as well as sex ratios of adults and sub-adults, were analyzed using a χ^2 goodness of fit test to determine whether the observed ratios significantly deviated from unity and are presented in

Species	number males	number females	MF ratio	chi_square_p
Apristurus ampliceps	0	6	0:1	
Apristurus sinensis	10	8	5:4	0.637352
Bythaelurus bachi	1	2	1:2	0.563703
Bythaelurus naylori	2	3	2:3	0.654721
Centrophorus granulosus	3	2	3:2	0.654721
Centrophorus squamosus	4	1	4:1	0.179712
Centroscymnus coelolepis	3	1	3:1	0.317311
Centroselachus crepidater	23	34	23:34	0.14512
Chimaera willwatchi	5	3	5:3	0.4795
Dalatias licha	0	34	0:1	
Deania calceus	11	26	11:26	0.013664
Deania hystricosa	3	6	1:02	**0.508**
Deania profundorum	13	31	13:31	0.006656
Deania sp	0	1	0:1	
Etmopterus (cf) sculptus	0	5	0:1	
Etmopterus alphus (cf)	0	1	0:1	
Etmopterus bigelowi	1	0	1:0	
Etmopterus granulosus	226	221	226:221	0.813051
Etmopterus pusillus	0	3	0:1	

Etmopterus sculptus	0	3	0:1	
Mitsukurina owstoni	1	0	1:0	
Pseudotriakis microdon	3	0	1:0	
Scymnodon plunketi	5	4	5:4	0.738883
Somniosus antarcticus	1	0	1:0	
Zameus squamulosus	1	0	1:0	

Table 3. Species encountered by trip, average by tow, average mid-water (MW) tow, and average bottom (BT) tow, for the 2012 (green), 2014 (blue), and 2024 (yellow) surveys.

** Centroscymnus coelolepis* and Etmopterus alphus* numbers from 2012 and 2014 are combined and averaged by total tows for 2012 and 2014

Table 1) List of chondrichthyan species encountered during the 2024 trip with sex and length (total length in mm) recorded for each specimen. M = male and F = female.

Species	**sex**	**minimum length**	**maximum length**
Apristurus ampliceps	F	452	528
Apristurus sinensis	F	605	696
Apristurus sinensis	M	591	757
Bythaelurus bachi	F	431	459
Bythaelurus bachi	M	651	651
Bythaelurus bachi	F	431	459
Bythaelurus bachi	M	651	651
Centrophorus granulosus	F	1171	1530
Centrophorus granulosus	M	1107	1171
Centrophorus squamosus	F	1241	1241
Centrophorus squamosus	M	973	1107
Centroscymnus coelolepis	F	964	964
Centroscymnus coelolepis	M	886	943
Centroselachus crepidater	F	89.2	1371
Centroselachus crepidater	M	349	887
Chimaera willwatchi	F	494	944
Chimaera willwatchi	M	552	833

Dalatias licha	F	935	1509
Deania calceus	F	499	1214
Deania calceus	M	816	961
Deania hystricosa	F	960	1132
Deania hystricosa	M	747	867
Deania profundorum	F	552	970
Deania profundorum	M	416	715
Etmopterus (cf) sculptus	F	384	545
Etmopterus alphus	F	436	436
Etmopterus bigelowi	M	315	315
Etmopterus granulosus	F	**75**	856
Etmopterus granulosus	M	62	879
Etmopterus pusillus	F	454	504
Etmopterus sculptus	F	121	506
Mitsukurina owstoni	M	3360	3360
Pseudotriakis microdon	M	1750	2341
Scymnodon plunketi	F	1430	1572
Scymnodon plunketi	M	807	1348
Somniosus antarcticus	M	1070	1070
Zameus squamulosus	M	503	503

Table 2. The overall proportions of each sex, as well as sex ratios of adults and sub-adults, were analyzed using a χ^2 goodness of fit test to determine whether the observed ratios significantly deviated from unity.

Species	number females	number males	F:M ratio	chi_square_p
Apristurus ampliceps	6	0	1:0	
Apristurus sinensis	8	10	4:5	0.637352
Bythaelurus bachi	2	1	2:1	0.563703
Bythaelurus naylori	3	2	3:2	0.654721
Centrophorus granulosus	2	3	2:3	0.654721
Centrophorus squamosus	1	4	1:4	0.179712
Centroscymnus coelolepis	1	3	1:3	0.317311
Centroselachus crepidater	34	23	34:23	0.14512
Chimaera willwatchi	3	5	3:5	0.4795
Dalatias licha	34	0	1:0	
Deania calceus	26	11	26:11	0.013664
Deania hystricosa	6	3	2:1	**0.508**
Deania profundorum	31	13	31:13	0.006656
Deania sp	1	0	1:0	
Etmopterus (cf) sculptus	5	0	1:0	

Etmopterus alphus (cf)	1	0	1:0	
Etmopterus bigelowi	0	1	0:1	
Etmopterus granulosus	221	226	221:226	0.813051
Etmopterus pusillus	3	0	1:0	
Etmopterus sculptus	3	0	1:0	
Mitsukurina owstoni	0	1	0:1	
Pseudotriakis microdon	0	3	0:1	
Scymnodon plunketi	4	5	4:5	0.738883
Somniosus antarcticus	0	1	0:1	
Zameus squamulosus	0	1	0:1	

Table 3. Species encountered by trip, average by tow, average mid-water (MW) tow, and average bottom (BT) tow, for the 2012 (green), 2014 (blue), and 2024 (yellow) surveys.

** Centroscymnus coelolepis* and Etmopterus alphus* numbers from 2012 and 2014 are combined and averaged by total tows for 2012 and 2014

Family	Species	Number encountered 2012	Average per tow	Average per MW tow	Average per BT tow	Number encountered	Average per tow	Average per MW tow	Average per BT tow	Number encountered	Average per tow	Average per MW tow	Average per BT tow
Scyliorhinidae	Apristurus ampliceps	27	0.077	0	0.964	4	0.011	0	0.143	8	0.023	0	0.286
Scyliorhinidae	Apristurus cf sinensis	0	0	0	0	3	0.009	0.003	0.071	0	0	0	0
Scyliorhinidae	Apristurus manocheri	8	0.023	0	0.286	2	0.006	0	0.071	1	0.003	0	0.036
Scyliorhinidae	Apristurus melanoasper	1	0.003	0	0.036	0	0	0	0	0	0	0	0
Scyliorhinidae	Apristurus sinensis	43	0.123	0.016	1.357	52	0.149	0.025	1.571	20	0.057	0.009	0.607
Scyliorhinidae	Bythaelurus bachi	1	0.003	0	0.036	11	0.031	0	0.393	3	0.009	0	0.107
Scyliorhinidae	Bythaelurus naylori	4	0.011	0	0.143	25	0.071	0.019	0.679	5	0.014	0.009	0.071
Centrophoridae	Centrophorus granulosus	28	0.08	0.012	0.857	6	0.017	0.003	0.179	5	0.014	0.009	0.071
Somniosidae	Centrophorus owstonii	21	0.06	0.003	0.714	24	0.069	0	0.857	0	0	0	0
Centrophoridae	Centrophorus squamosus	41	0.117	0.022	1.214	34	0.097	0.016	1.036	6	0.017	0.019	0
Somniosidae	Centroscymnus coelolepis**	0.118	0	0	0	0.118	0	0	0	4	0.011	0.003	0.107
Somniosidae	Centroselachus crepidater	182	0.52	0.075	5.643	121	0.346	0.071	3.5	61	0.174	0.106	0.964
Chimaeridae	Chimaera buccanigella	1	0.003	0	0.036	0	0	0	0	0	0	0	0
Chimaeridae	Chimaera didierae	1	0.003	0	0.036	0	0	0	0	0	0	0	0
Chimaeridae	Chimaera willwatchi	22	0.063	0.009	0.679	29	0.083	0.016	0.607	8	0.023	0	0.286
Dalatiidae	Dalatias licha	141	0.403	0.099	3.893	37	0.106	0.087	0.321	38	0.109	0.106	0.143
Centrophoridae	Deania calceus	42	0.12	0.006	1.429	0	0	0	0	39	0.111	0.065	0.643
Centrophoridae	Deania hystricosa	0	0	0	0	0	0	0	0	9	0.026	0.028	0
Centrophoridae	Deania profundorum	38	0.109	0	1.357	0	0	0	0	49	0.14	0.152	0
Etmopteridae	Etmopterus (cf) sculptus	0	0	0	0	0	0	0	0	5	0.014	0.016	0
Etmopteridae	Etmopterus alphus*	0.014	0	0	0	0.014	0	0	0	1	0.003	0.003	0
Etmopteridae	Etmopterus bigelowi	1	0.003	0	0.036	0	0	0	0	2	0.006	0.006	0
Etmopteridae	Etmopterus cf compagnoi	0	0	0	0	2	0.006	0	0.071	1	0.003	0.003	0
Etmopteridae	Etmopterus granulosus	1585	4.529	0.404	51.964	1010	2.886	0.95	25.143	459	1.311	0.301	12.929
Etmopteridae	Etmopterus pusillus	7	0.02	0	0.25	6	0.017	0.009	0.107	6	0.017	0.019	0
Etmopteridae	Etmopterus sculptus	20	0.057	0	0.714	0	0	0	0	4	0.011	0.009	0.036
Hexanchidae	Hexanchus griseus	0	0	0	0	0	0	0	0	1	0.003	0.003	0
Chimaeridae	Hydrolagus sp nov	2	0.006	0	0.071	1	0.003	0	0.036	0	0	0	0
Mitsukurinidae	Mitsukurina owstoni	0	0	0	0	0	0	0	0	1	0.003	0.003	0
Glaucostegidae	Plesiobatis cf daviesi	0	0	0	0	0	0	0	0	1	0.003	0.003	0
Pseudotriakidae	Pseudotriakis microdon	28	0.08	0	1	0	0	0	0	3	0.009	0	0.107
Somniosidae	rostratus sp	0	0	0	0	1	0.003	0.003	0	0	0	0	0
Somniosidae	Scymnodon plunketi	46	0.131	0.019	1.429	4	0.011	0	0.143	10	0.029	0.022	0.107
Somniosidae	Somniosus antarcticus	0	0	0	0	0	0	0	0	1	0.003	0	0.036
Somniosidae	Zameus squamulosus	5	0.014	0.006	0.107	0	0	0	0	1	0.003	0	0.036

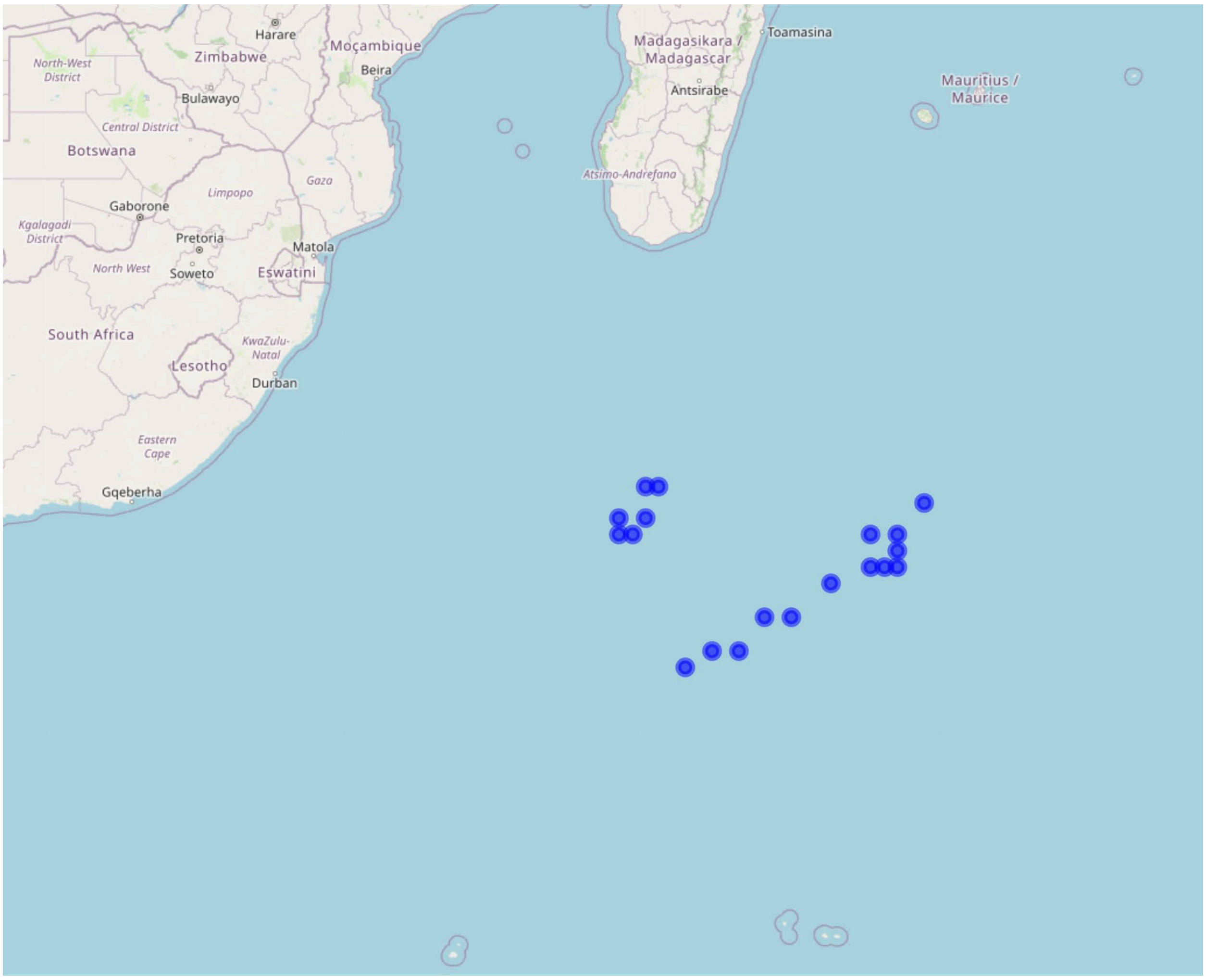


Figure 1. Map of the area fished in the Southwestern Indian Ocean.

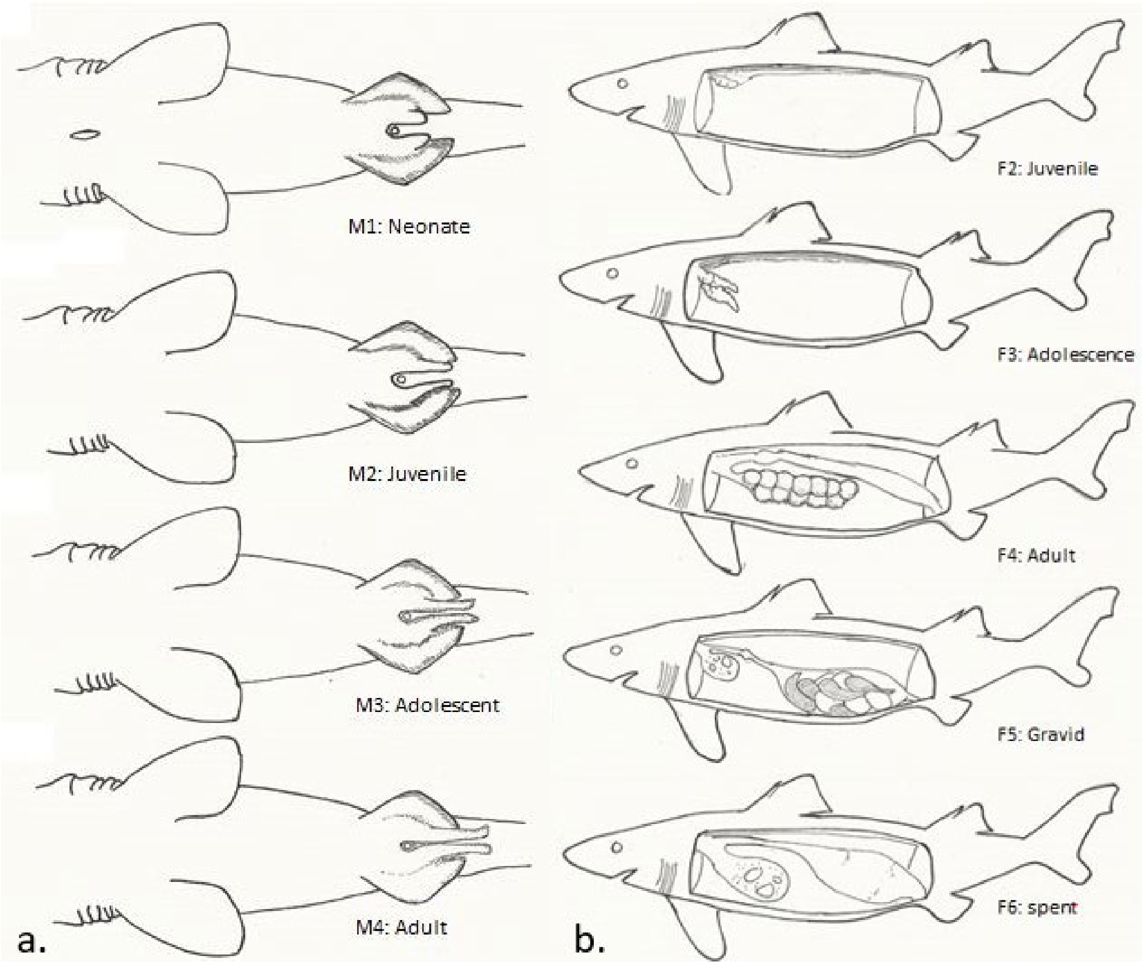


Figure 2. Illustration of maturity ranking system for sharks a) males, b) females. Illustration by P.J. Clerkin.

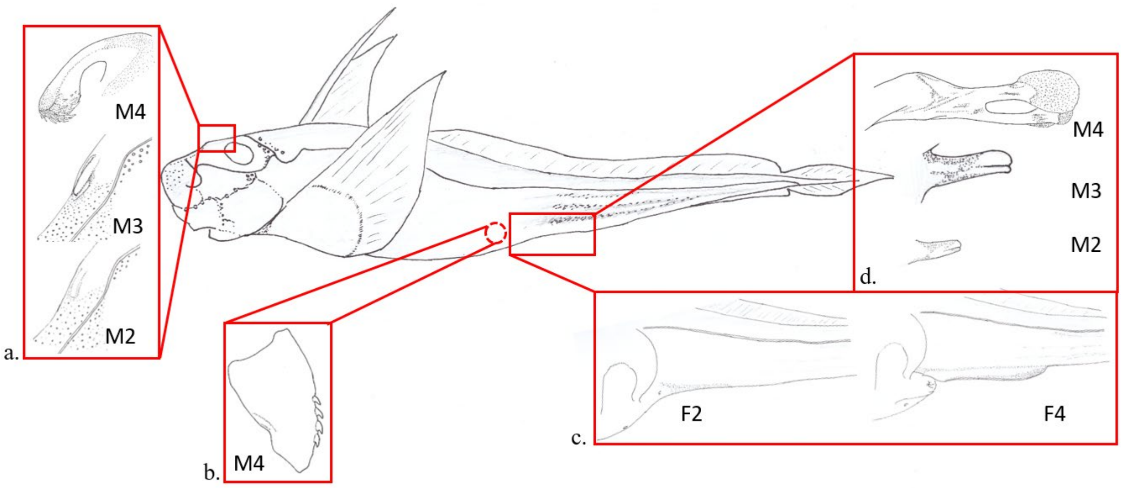


Figure 3. Illustration of maturity ranking system for chimaeroids showing stages of development of a) frontal tenaculum, b) pre-pelvic tenaculum, c) anal pad, and d), claspers. Illustration by P.J. Clerkin.

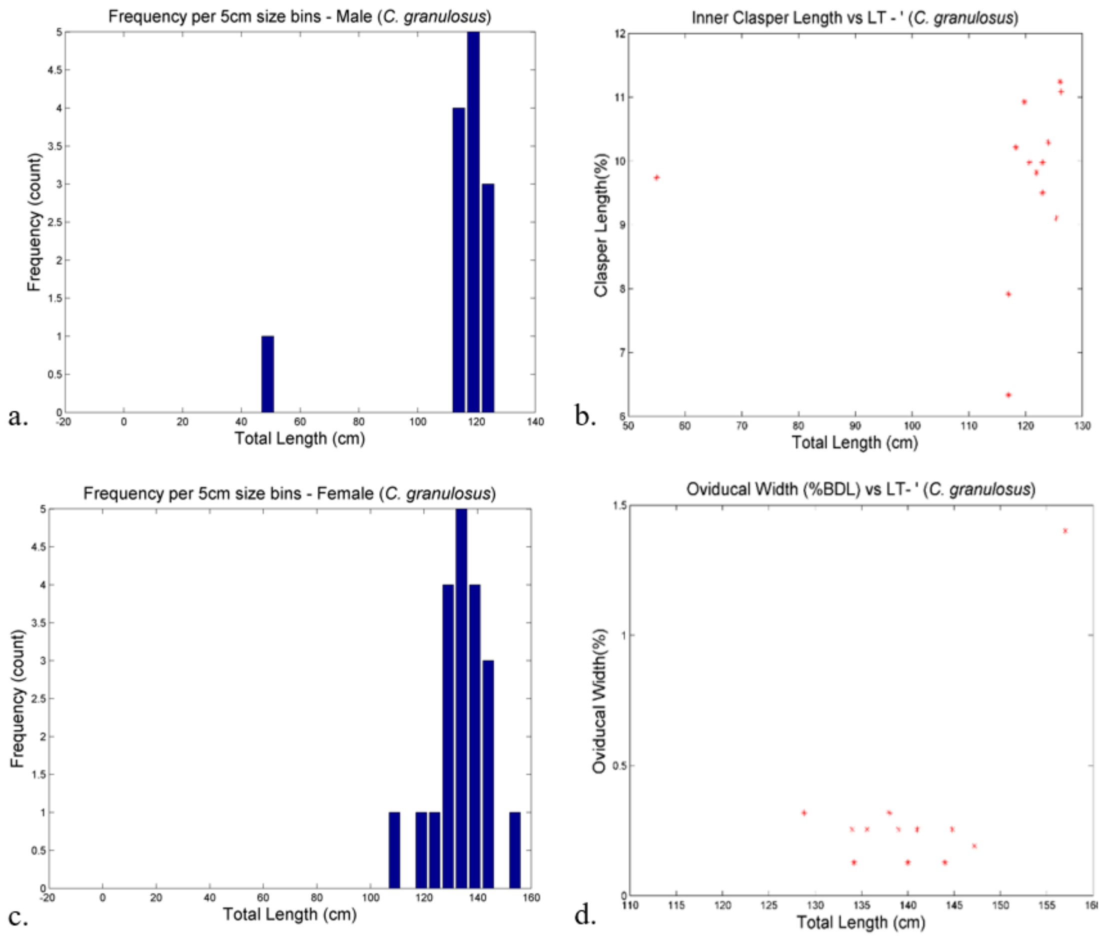


Figure 4. *Centrophorus granulosus*: a) size distribution of males, b) relationship between inner clasper length (%LT) and LT (males), c) size distribution of females, d) relationship between shell gland width (%LT) and LT (females) taken during the 2012 and 2014 surveys

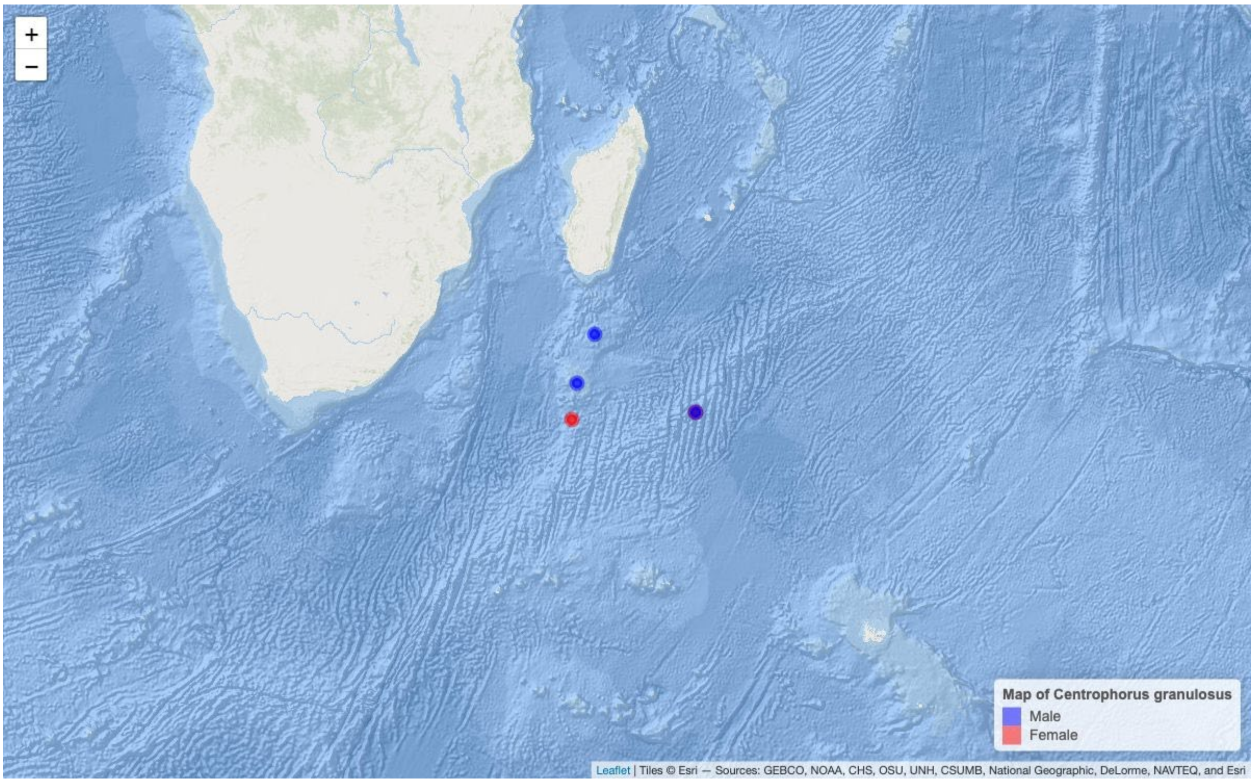


Figure 5. Distribution of *Centrophorus granulosus* males (blue) and females (red) encountered during the 2024 survey

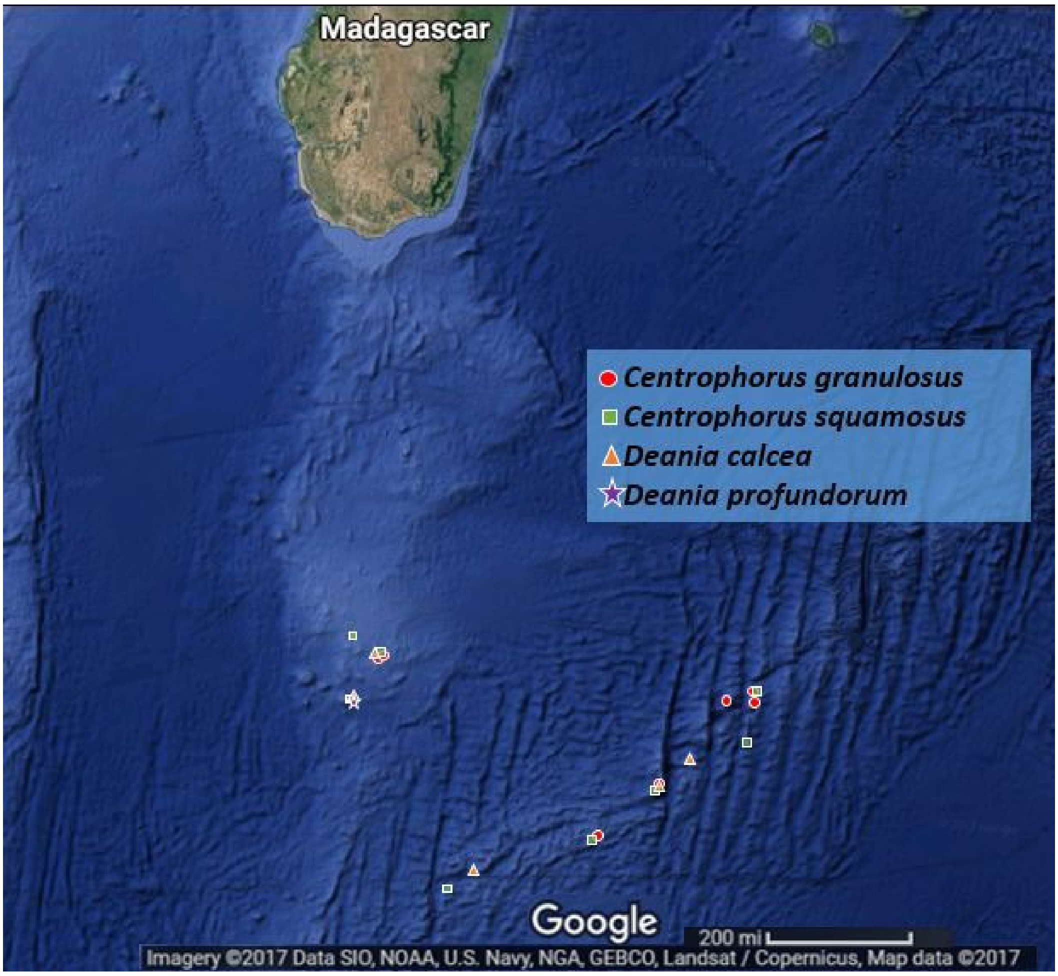


Figure 6. Distribution of the family Centrophoridae of this study: *Centrophorus granulosus* (red circle), *Centrophorus squamosus* (green square), *Deania calcea* (orange triangle), and *Deania profundorum* (purple star) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

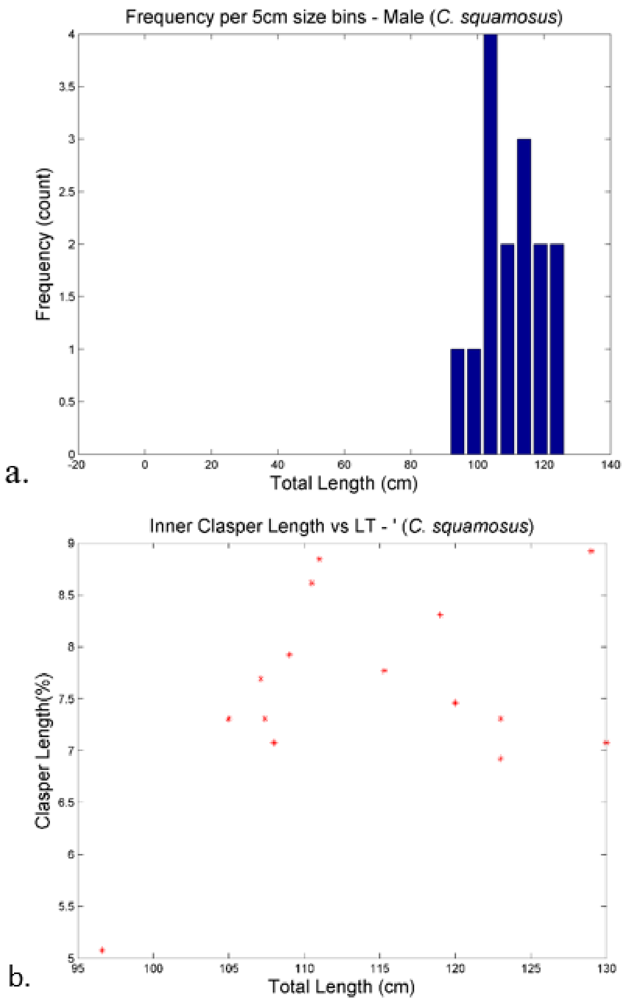


Figure 7. *Centrophorus squamosus*: a) size distribution of males, b) relationship between inner clasper length (%L_T) and L_T (males) from 2012 and 2-14 surveys.

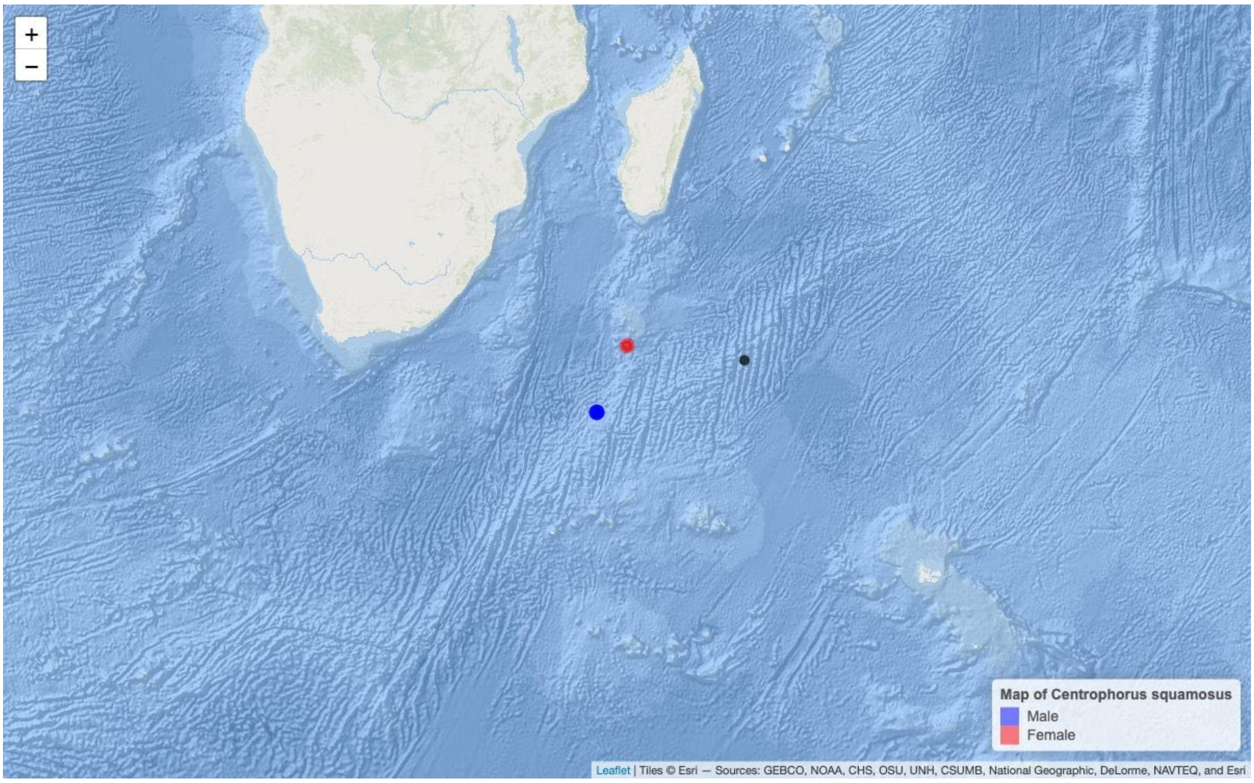


Figure 8. Distribution of *Centrophorus squamosus* males (blue), females (red), and unsex (black) encountered during the 2024 survey

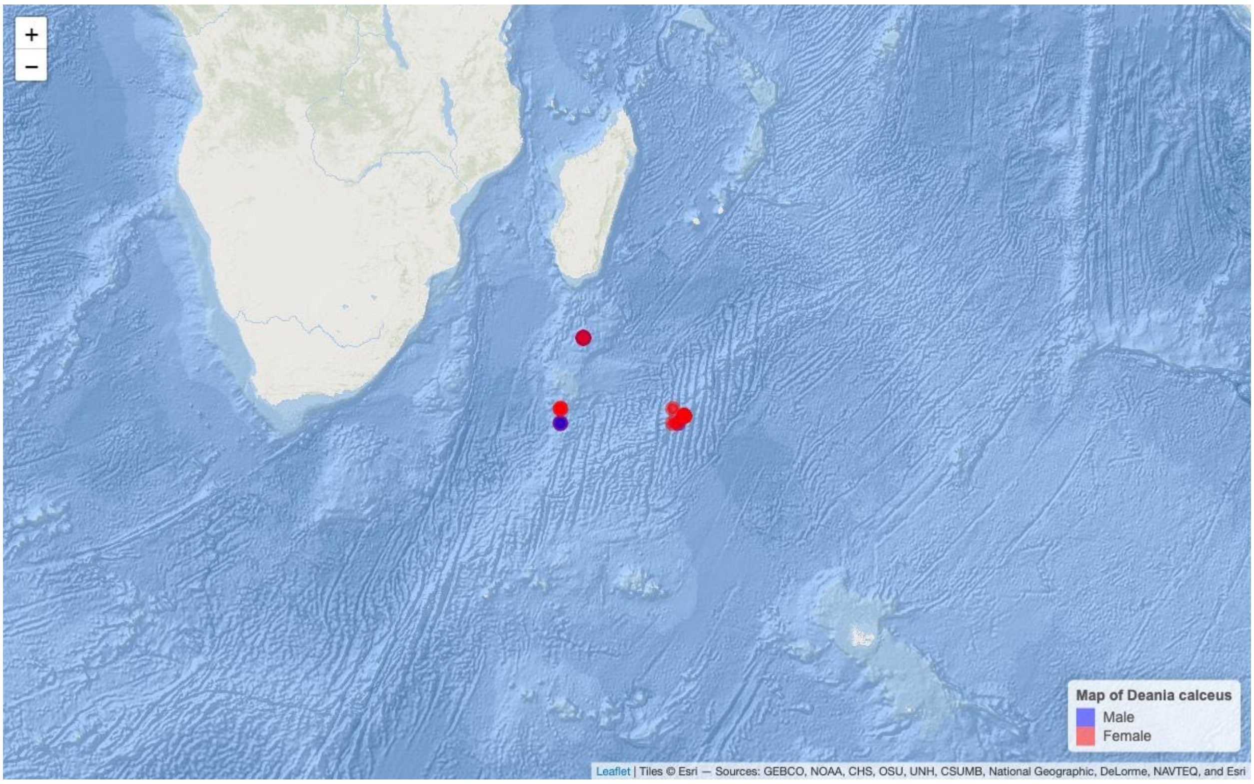


Figure 9. Distribution of *Deania calceus* males (blue) and females (red) encountered during the 2024 survey

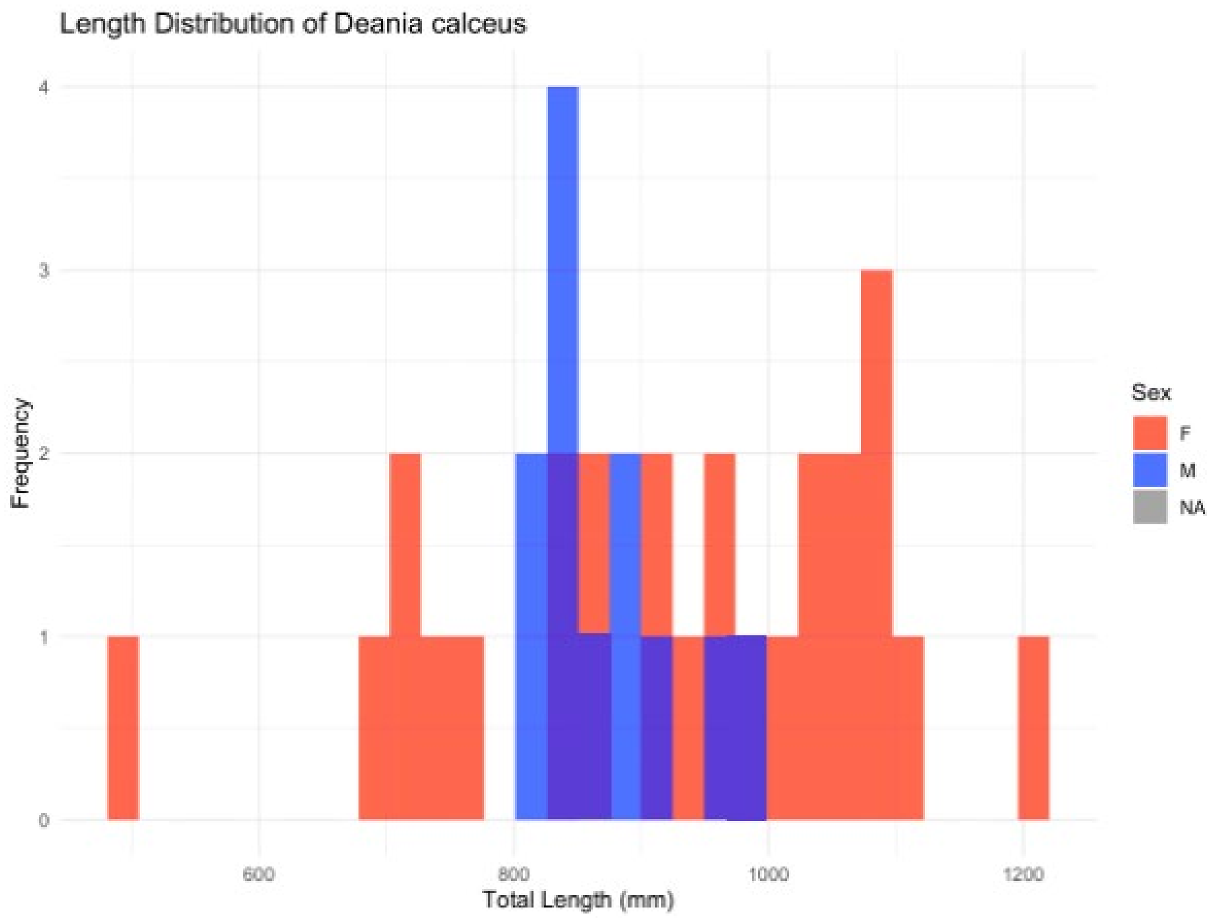


Figure 10. *Deania calcus*: a) size distribution of males (blue), females (red), and unsexed (grey) from the 2024 survey

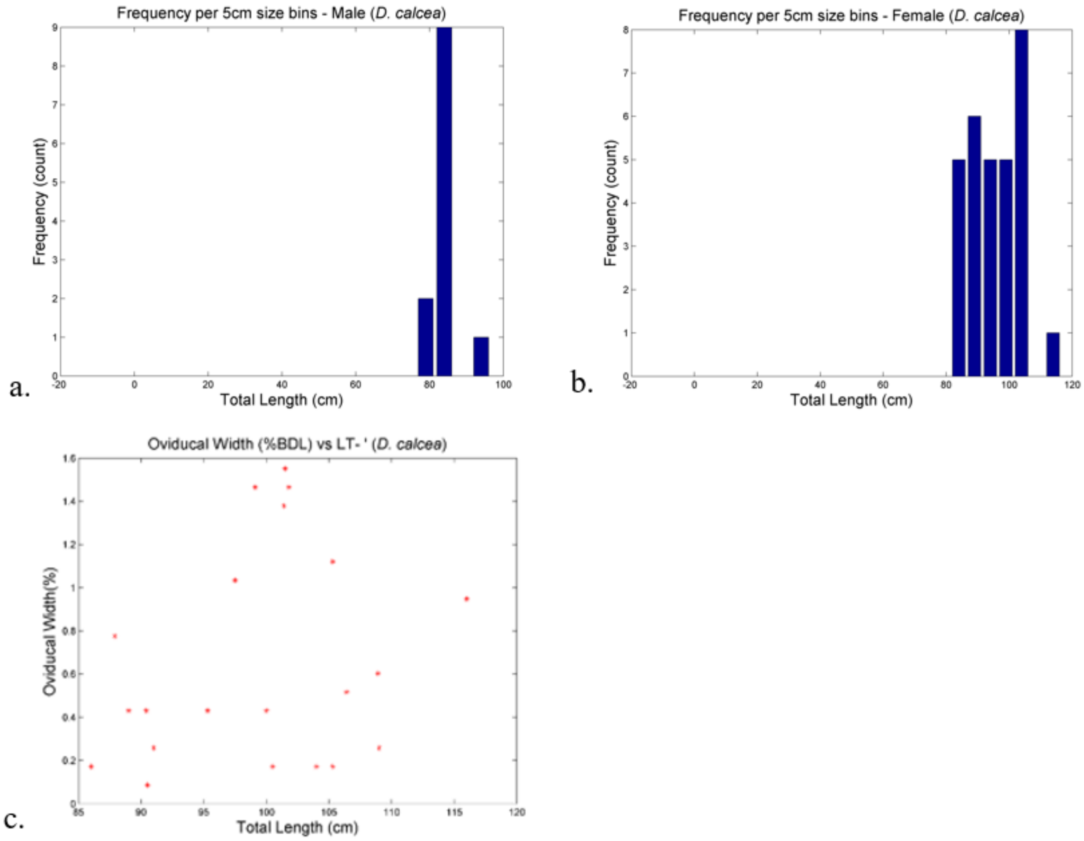


Figure 11. *Deania calcus*: a) size distribution of males, b) size distribution of females, c) relationship between shell gland width (%LT) and LT (females) taken during the 2012 and 2014 surveys

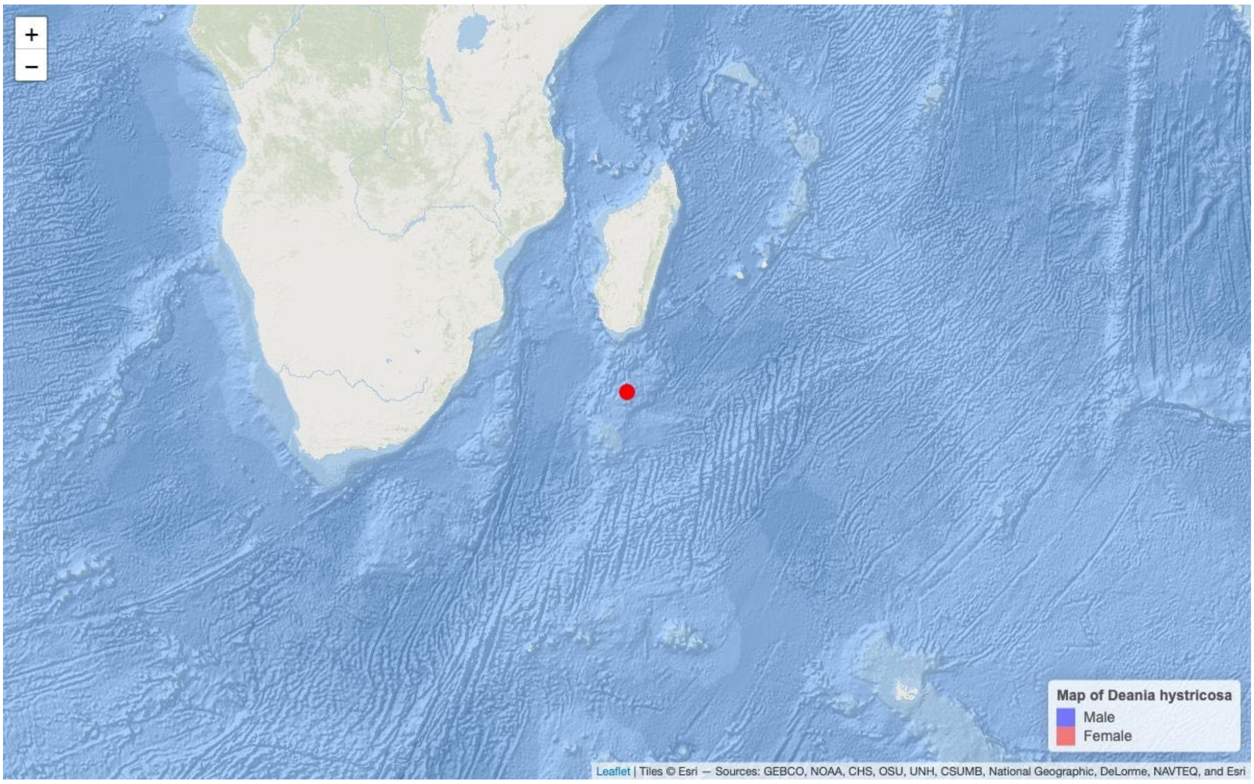


Figure 12. location of *Deania hystricosa* female encountered during the 2024 survey

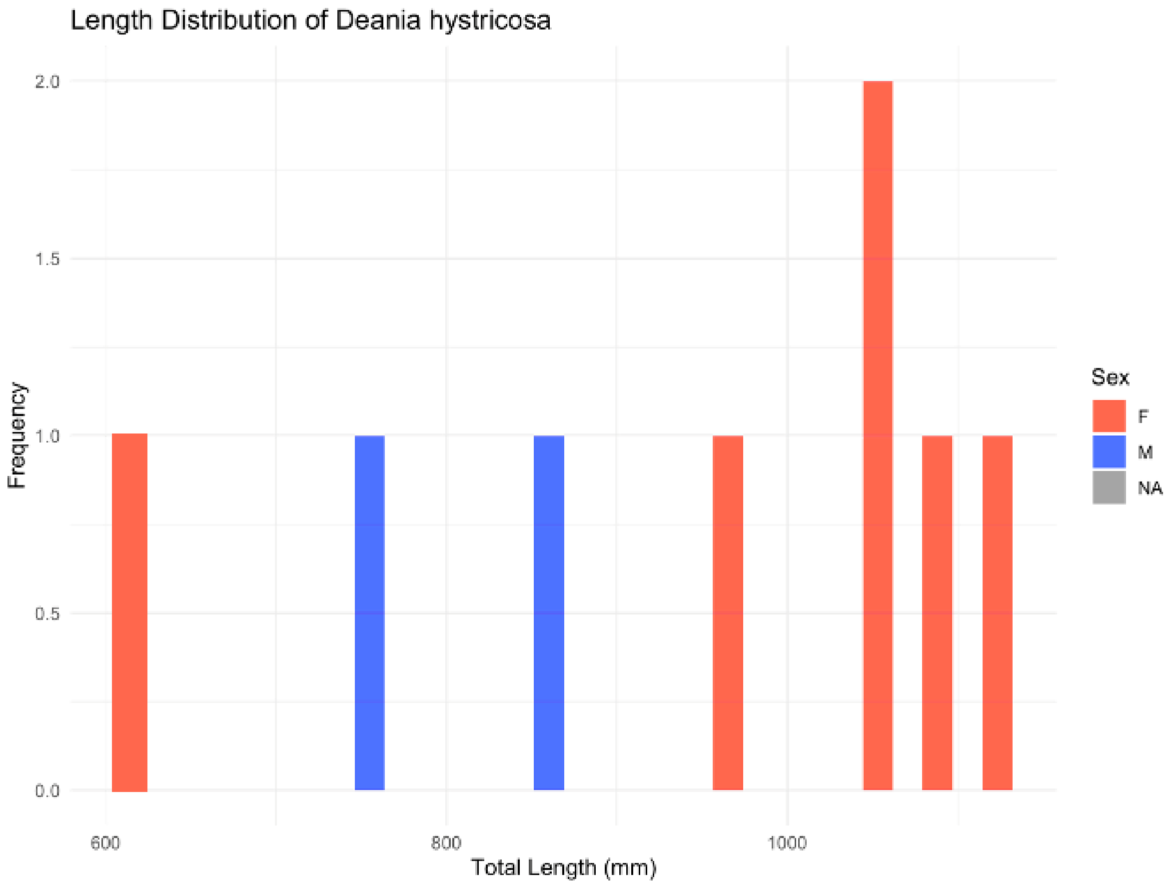


Figure 13. *Deania hystricosa*:: a) size distribution of males (blue), females (red), grey unsexed from the 2024 survey

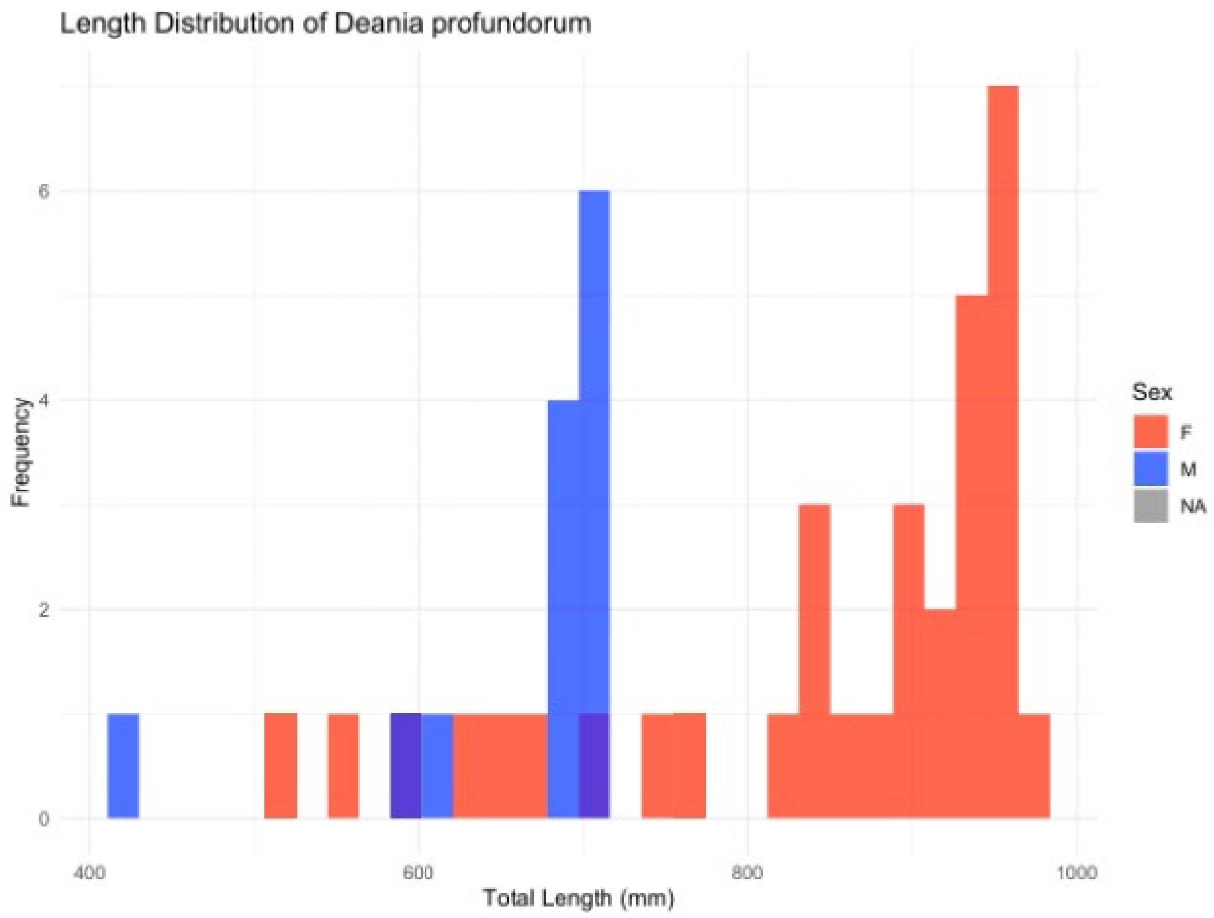
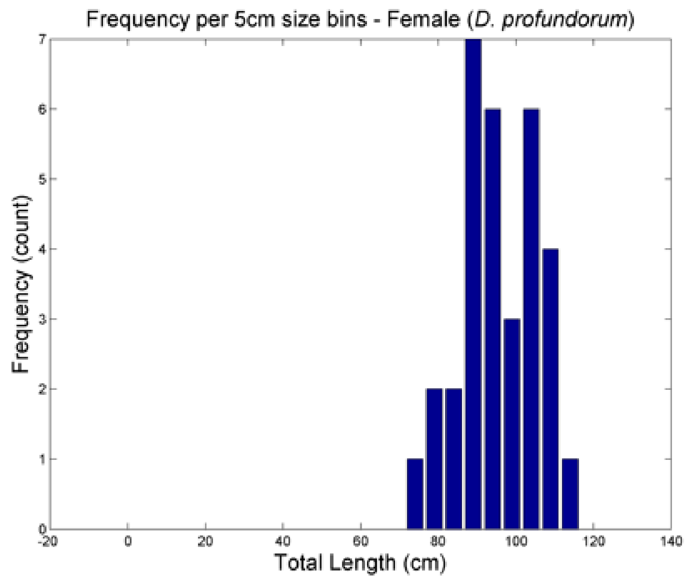
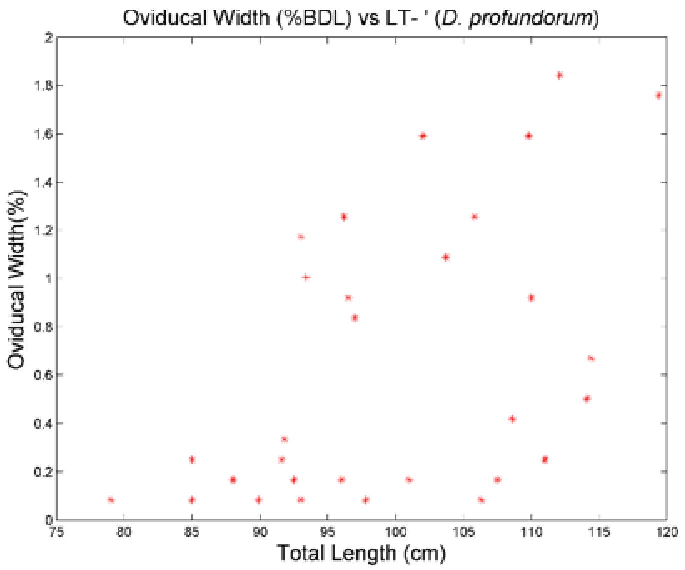


Figure 14 *Deania profundorum*: size distribution of males (blue) and females (red) from the 2024 survey



a.



b.

Figure 15 *Deania profundorum*: a) size distribution of males, b) size distribution of females, c) relationship between shell gland width (%LT) and LT (females) taken during the 2012 and 2014 surveys

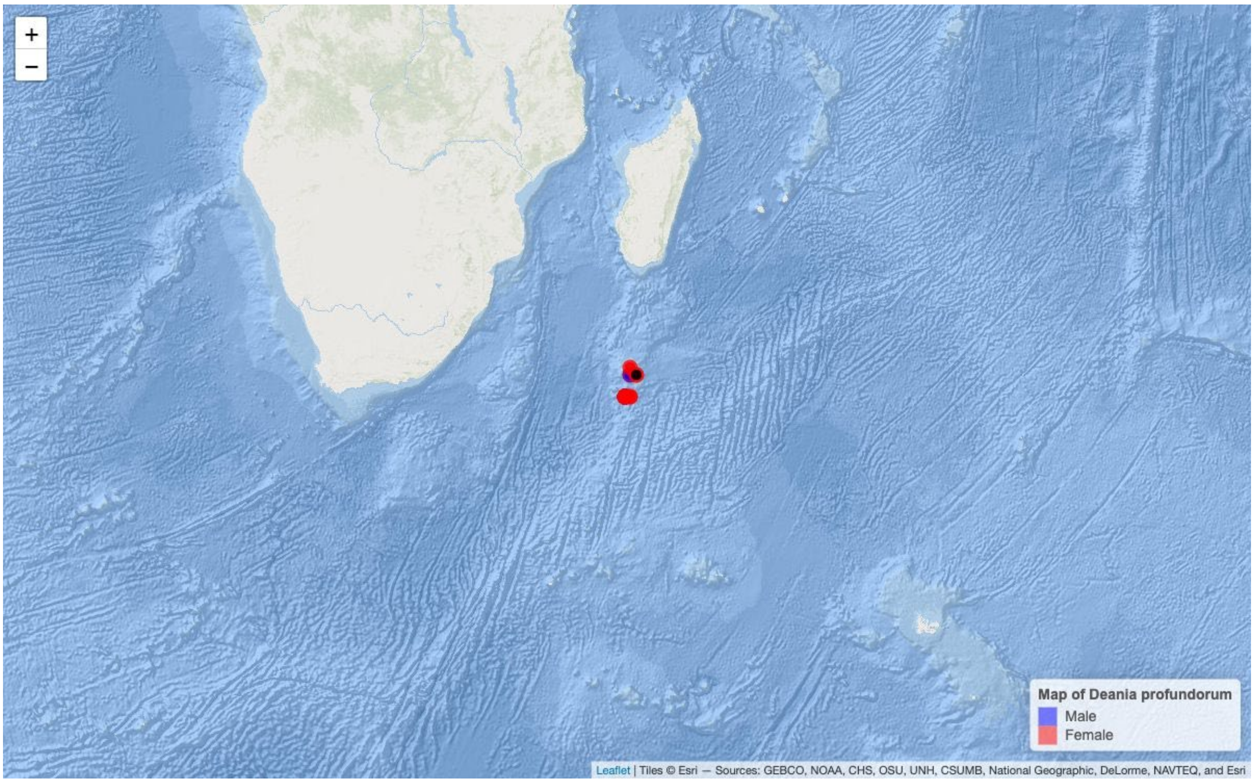


Figure 16: Distribution of *Deania profundorum* males (blue) and females (red) encountered during the 2024 survey

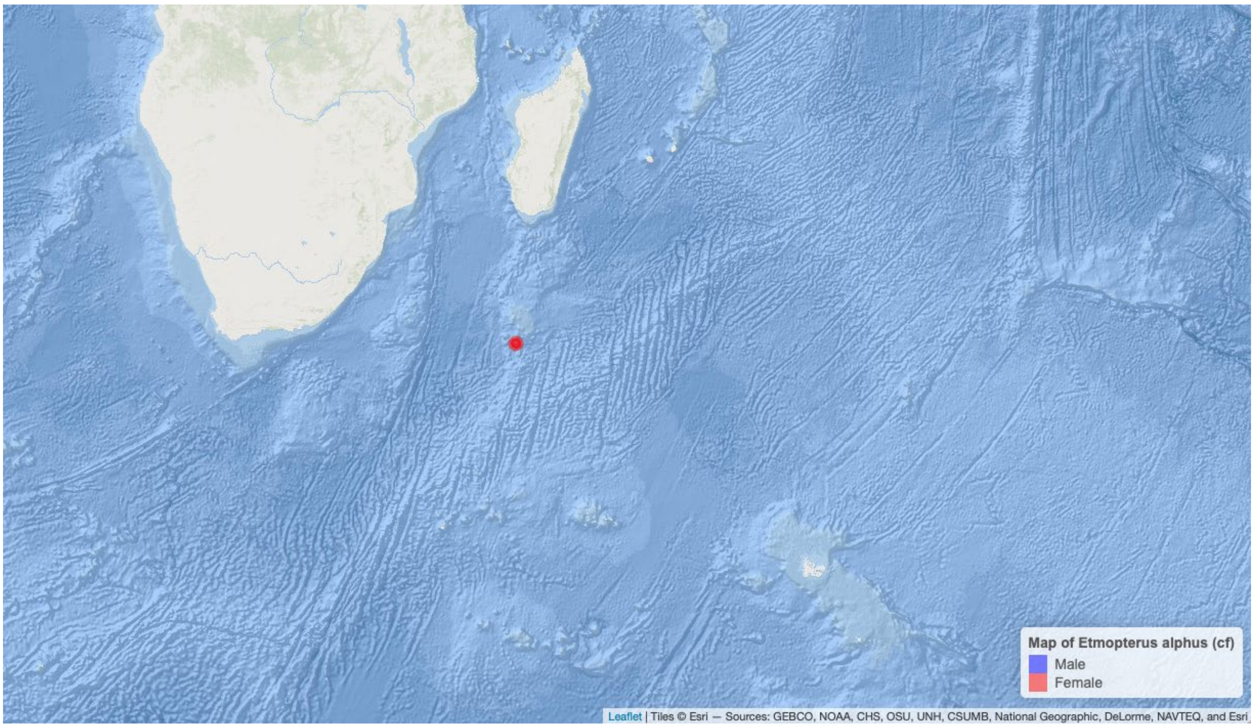


Figure 17: Distribution of *Etmtoperus alphus* female encountered during the 2024 survey

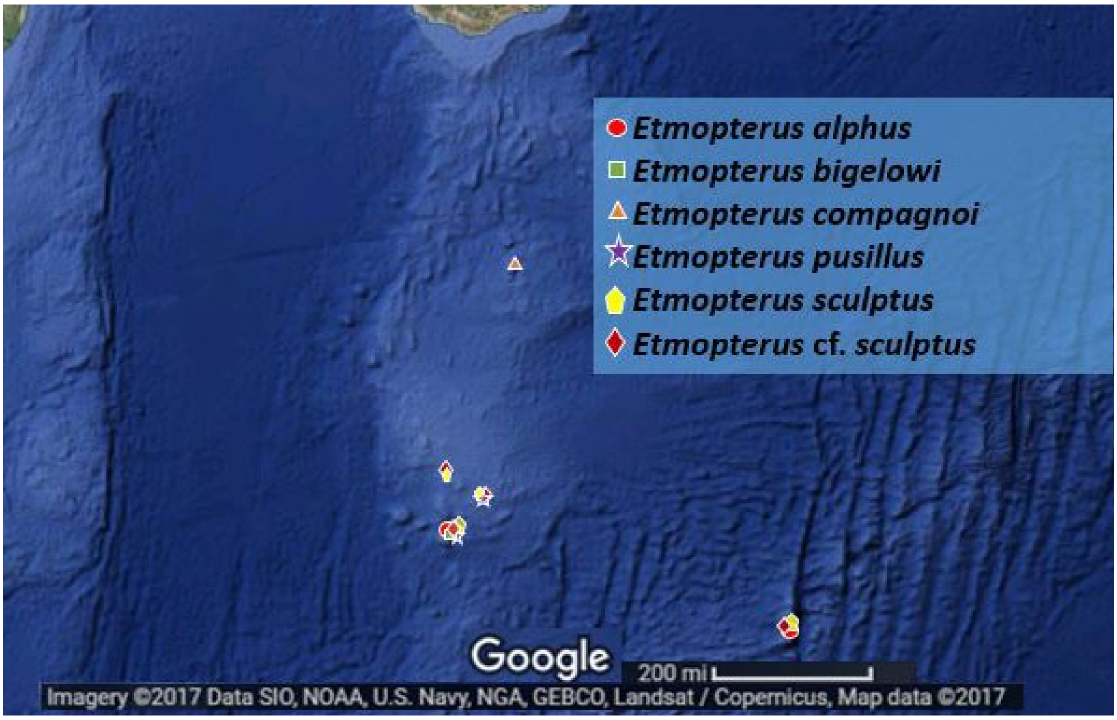


Figure 18. Distribution of the family Etmopteridae (sans *E. granulosus*. See figure 30): *Etmopterus alphus* (red circle), *E. bigelowi* (green square), *E. compagnoi* (orange triangle), *E. pusillus* (purple star), *E. sculptus* (yellow pentagon), *E.* cf. *sculptus* (maroon diamond) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

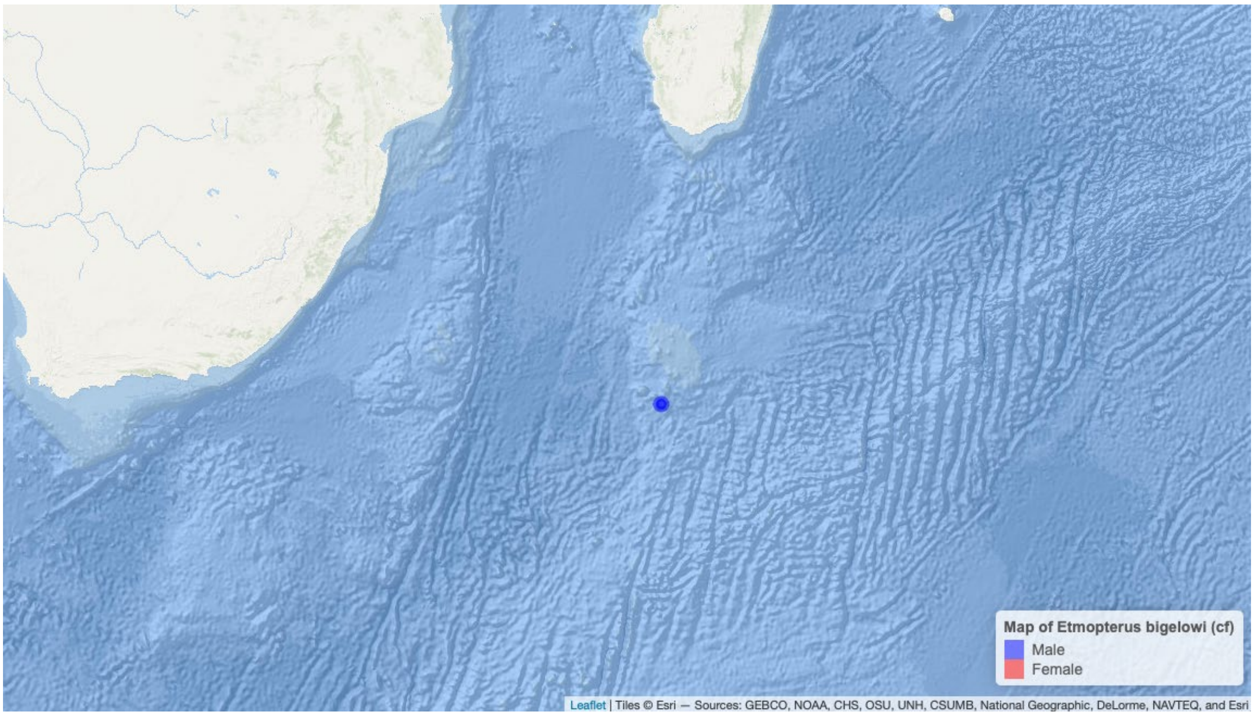


Figure 19: Distribution of *Etmopterus alphus* male encountered during the 2024 survey

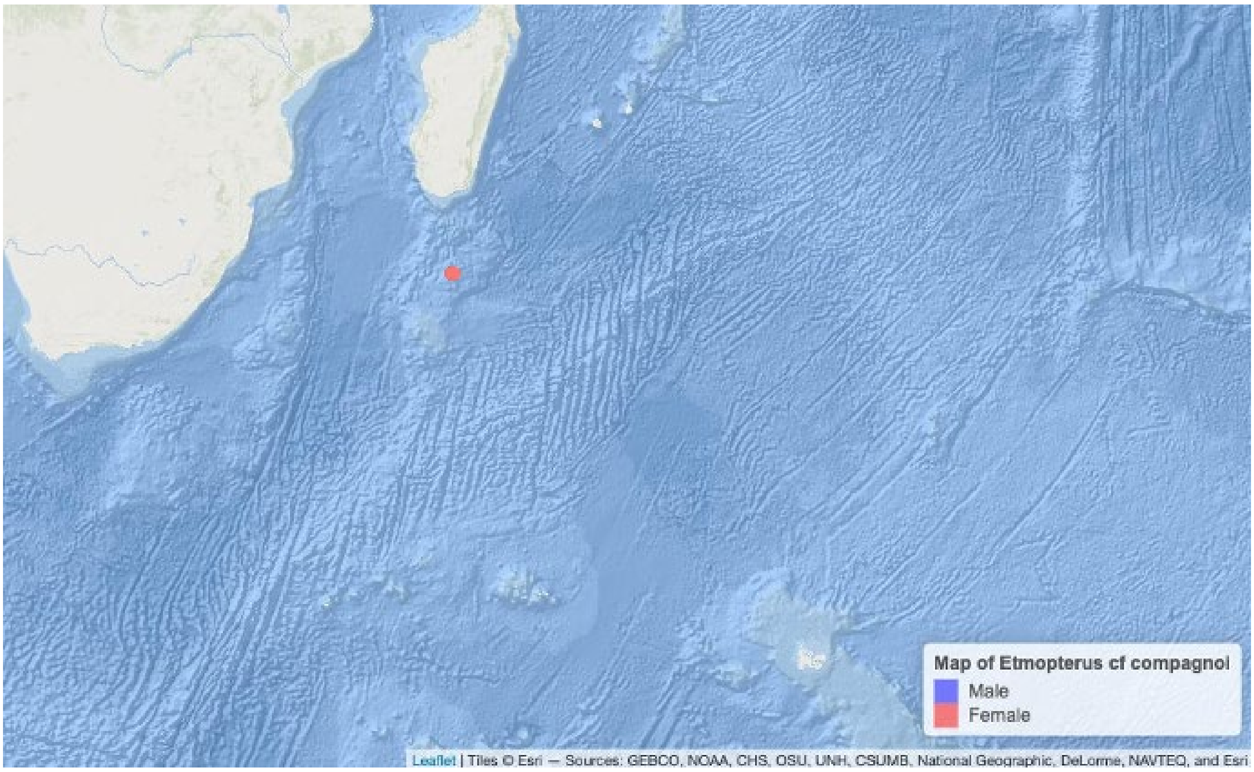


Figure 20: Distribution of *Etmopterus* cf *compagnoi* female encountered during the 2024 survey

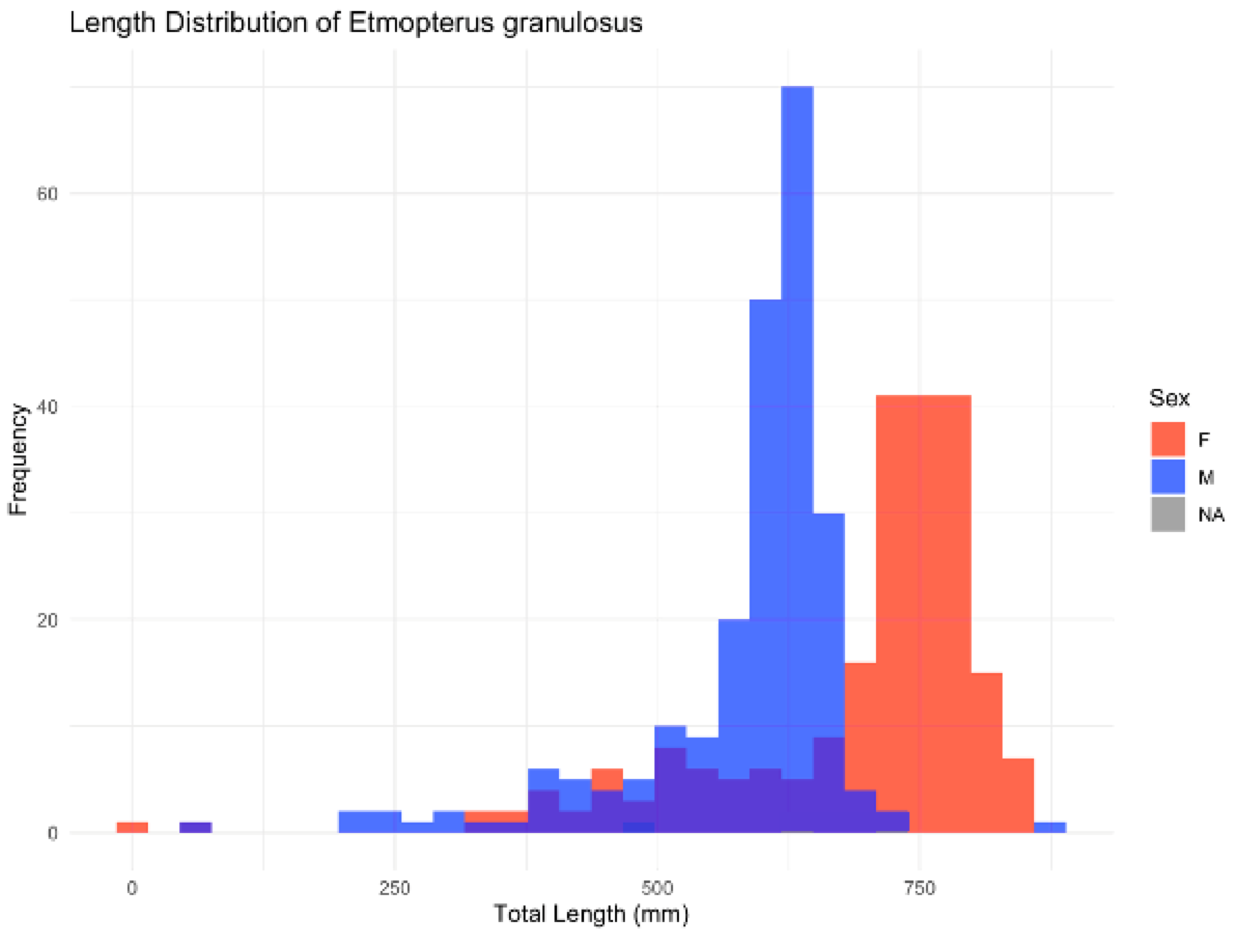


Figure 21. Etmopterus granulosus: size distribution of males (blue) and females (red) from the 2024 survey

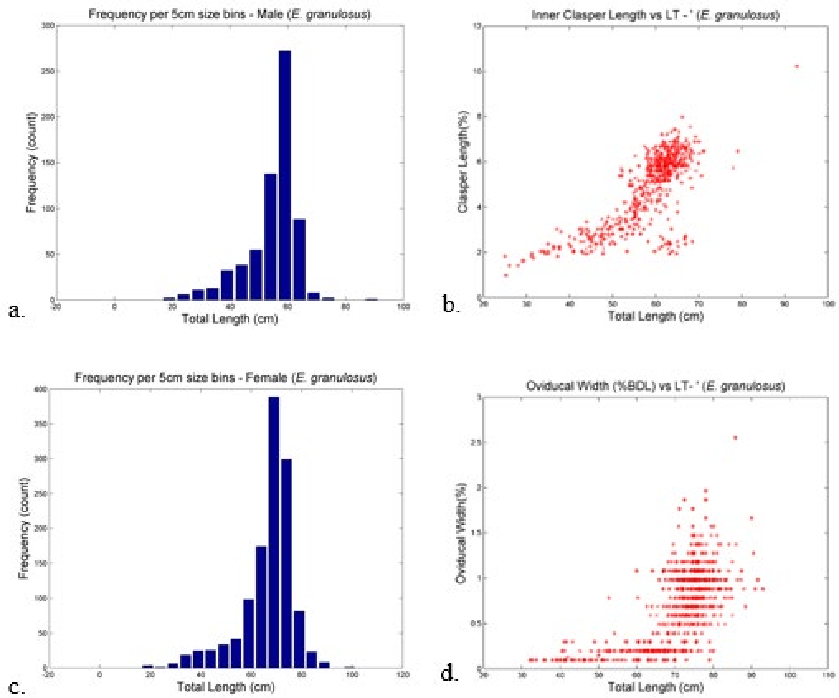


Figure 22. *Etmopterus granulosus*: a) size distribution of males, b) relationship between inner clasper length (%L_T) and L_T (males), c) size distribution of the females, and d) relationship between shell gland width (%L_T) and L_T (females) from 2012 and 2-14 surveys.

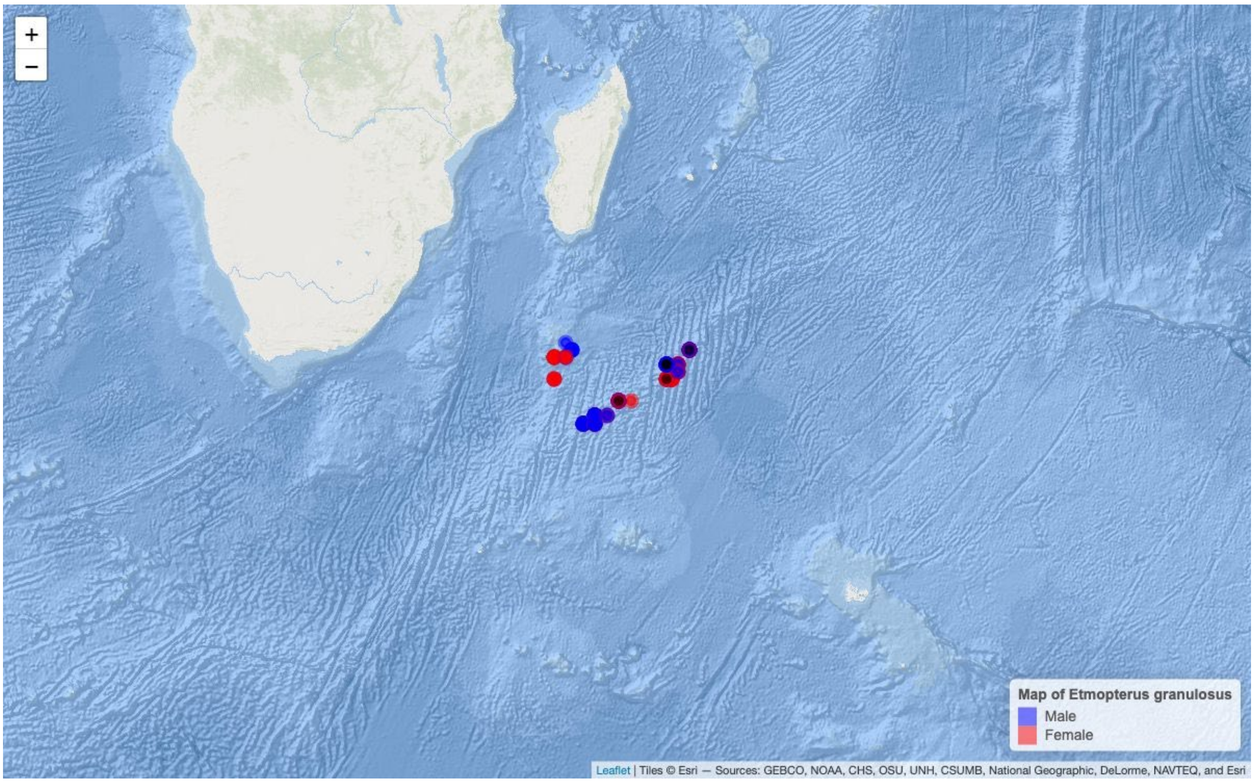


Figure 23. Distribution of *Etmopterus granulosus* males (blue) and females (red) encountered during the 2024 survey

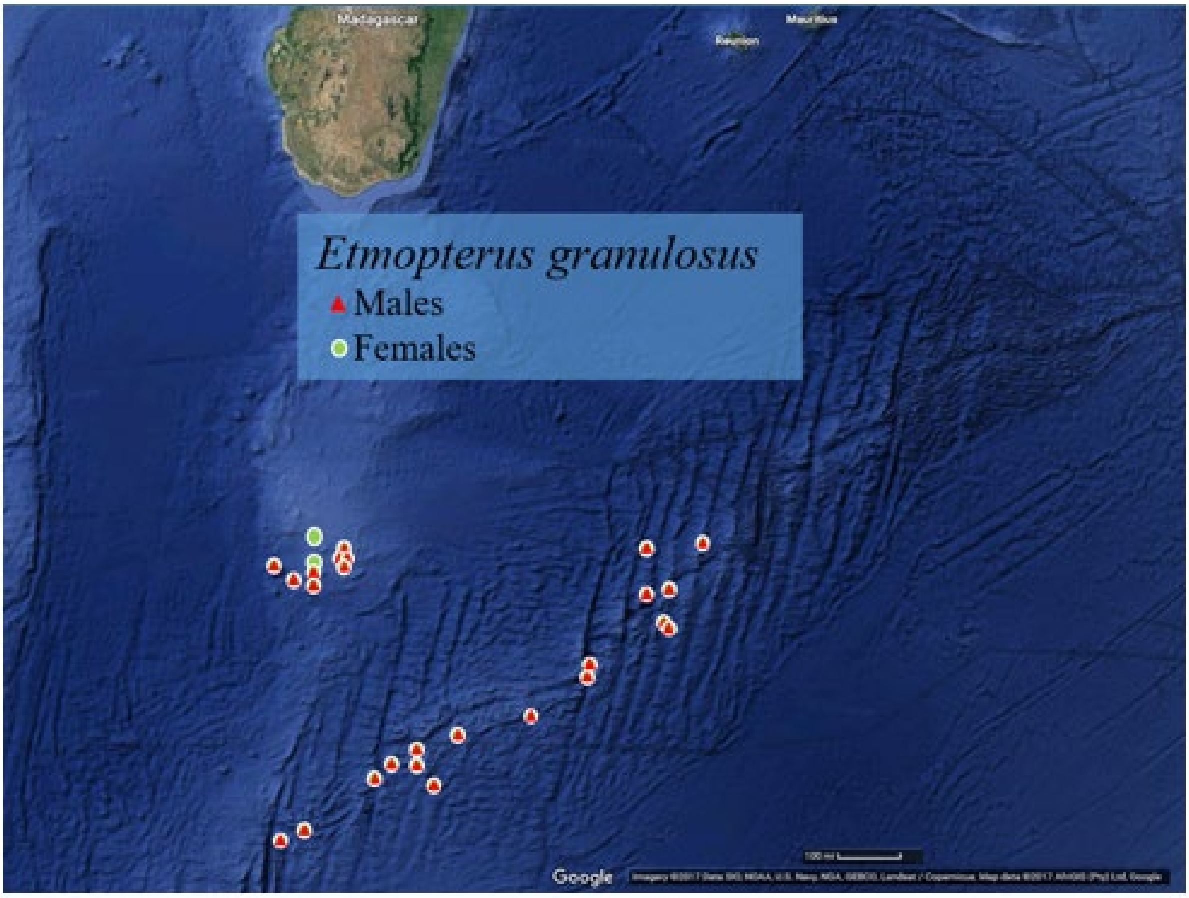


Figure 24 Distribution of *Etmopterus granulosus* (red triangles) and females (green circles) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

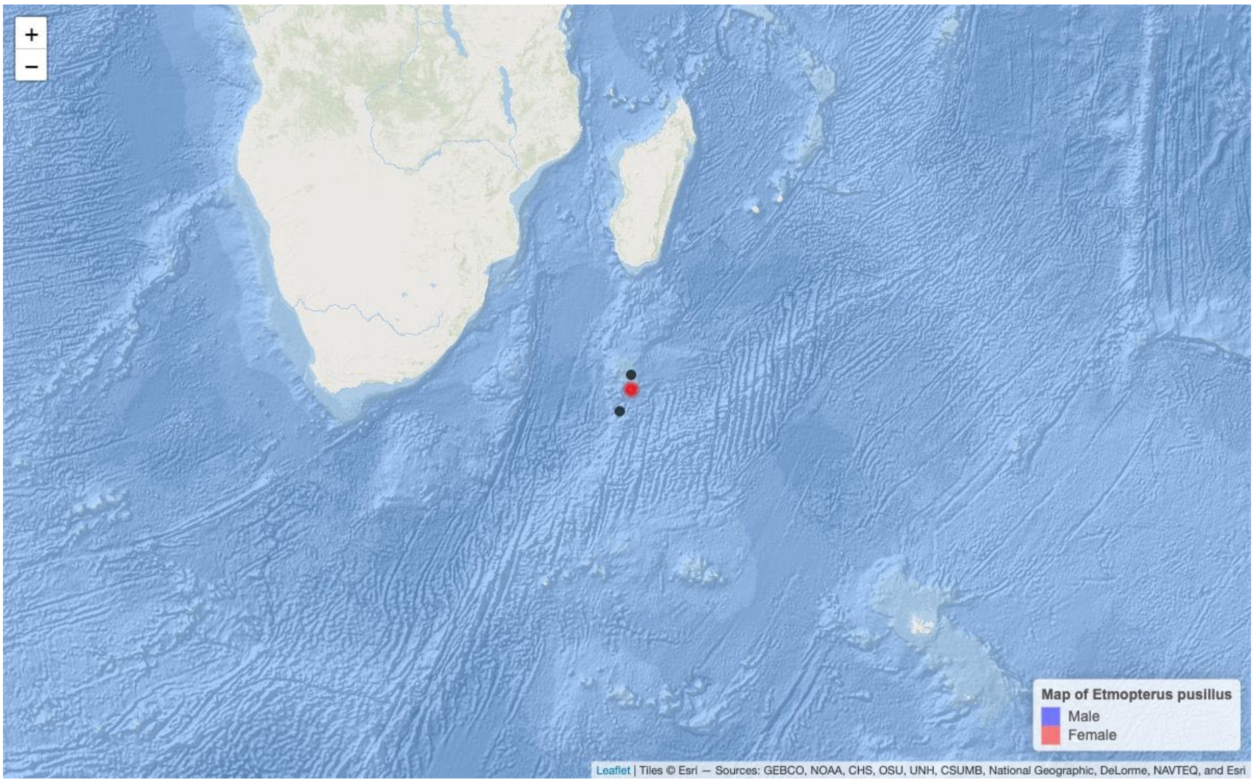


Figure 25. Distribution of *Etmopterus pusillus* females (red) and unsex (black) encountered during the 2024 survey

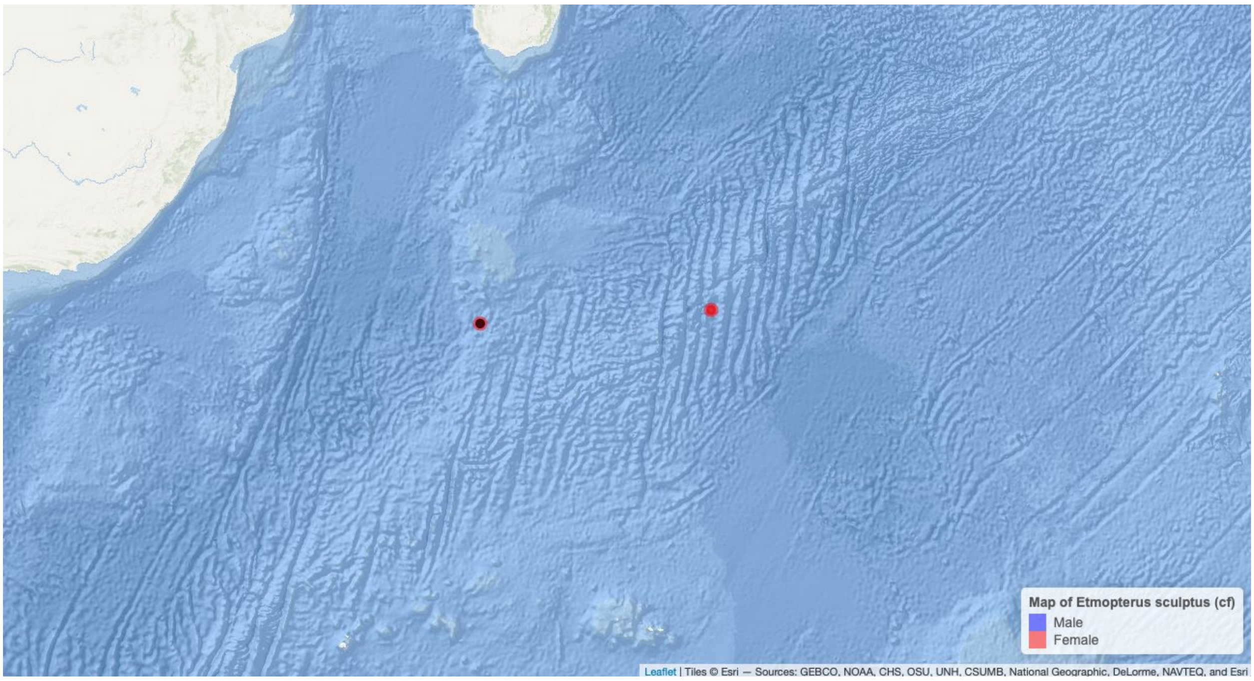


Figure 26. Distribution of *Etmopterus sculptus* females (red) encountered during the 2024 survey

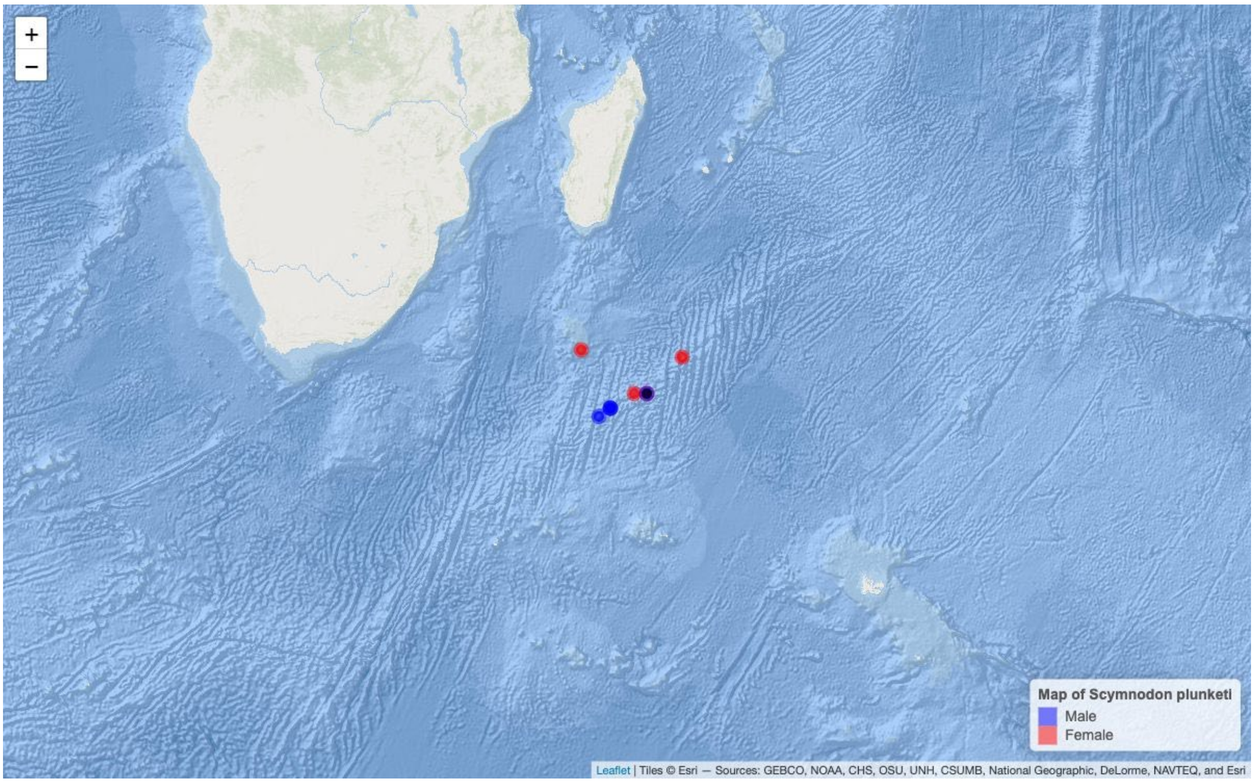


Figure 27. Distribution of *Scymnodon plunketi* males (blue) and females (red) encountered during the 2024 survey

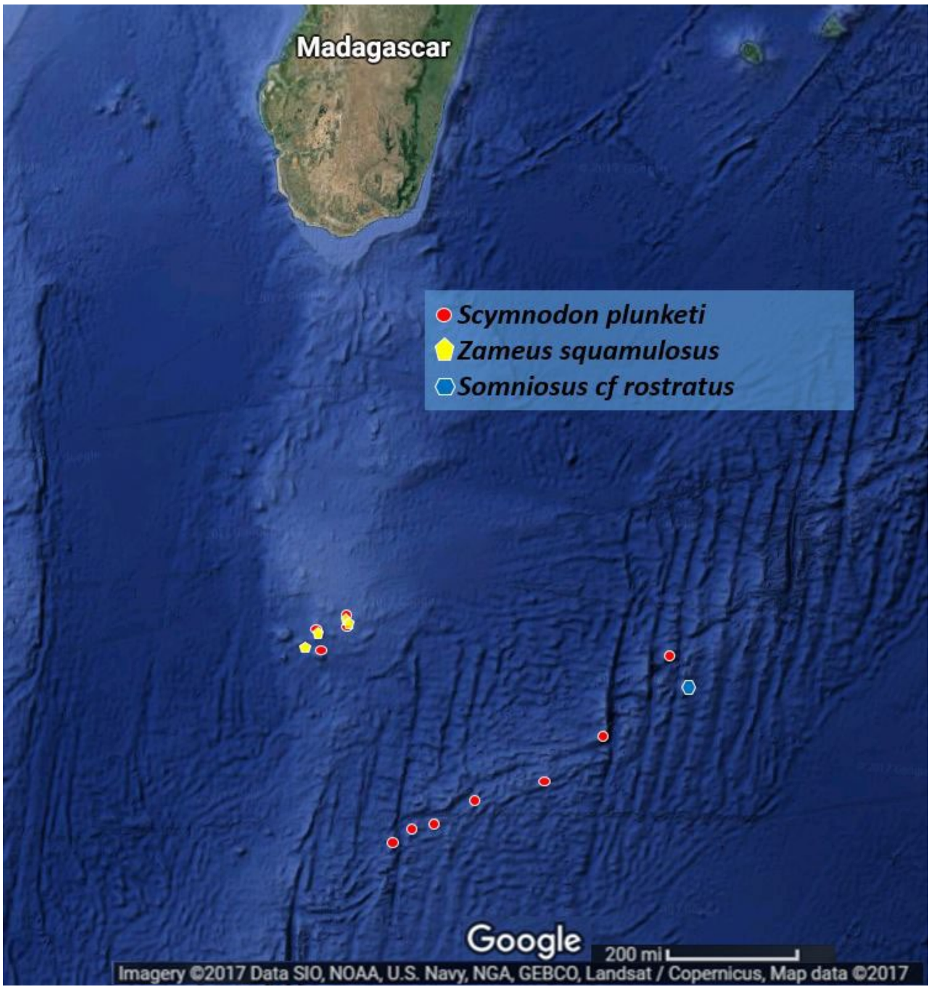


Figure 28. Distribution of the family Somniosidae (sans *Centroscymnus, Centroselachus,* and *Dalatias*): *Scymnodon plunketi* (red circle), *Zameus squamulosus* (yellow pentagon), and *Somniosus*

cf *rostratus* (blue hexagon) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

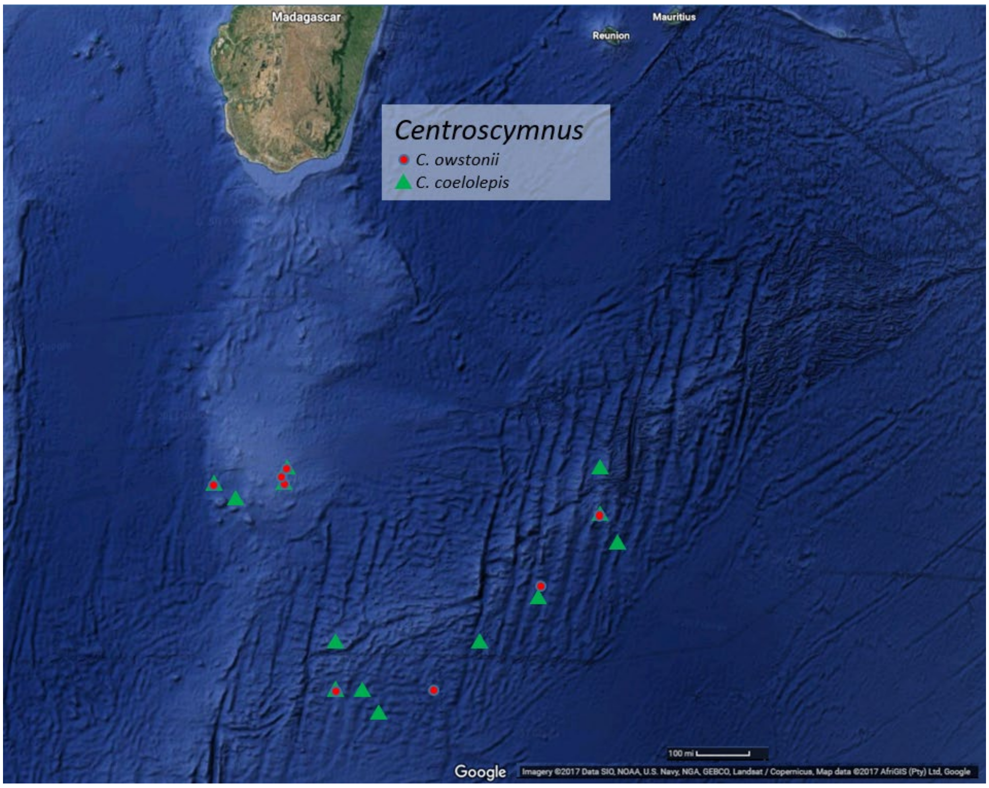


Figure 29. Distribution of the genus *Centroscymnus*: *C. coelolepis* (green triangle) and *C. owstonii* (red circle) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

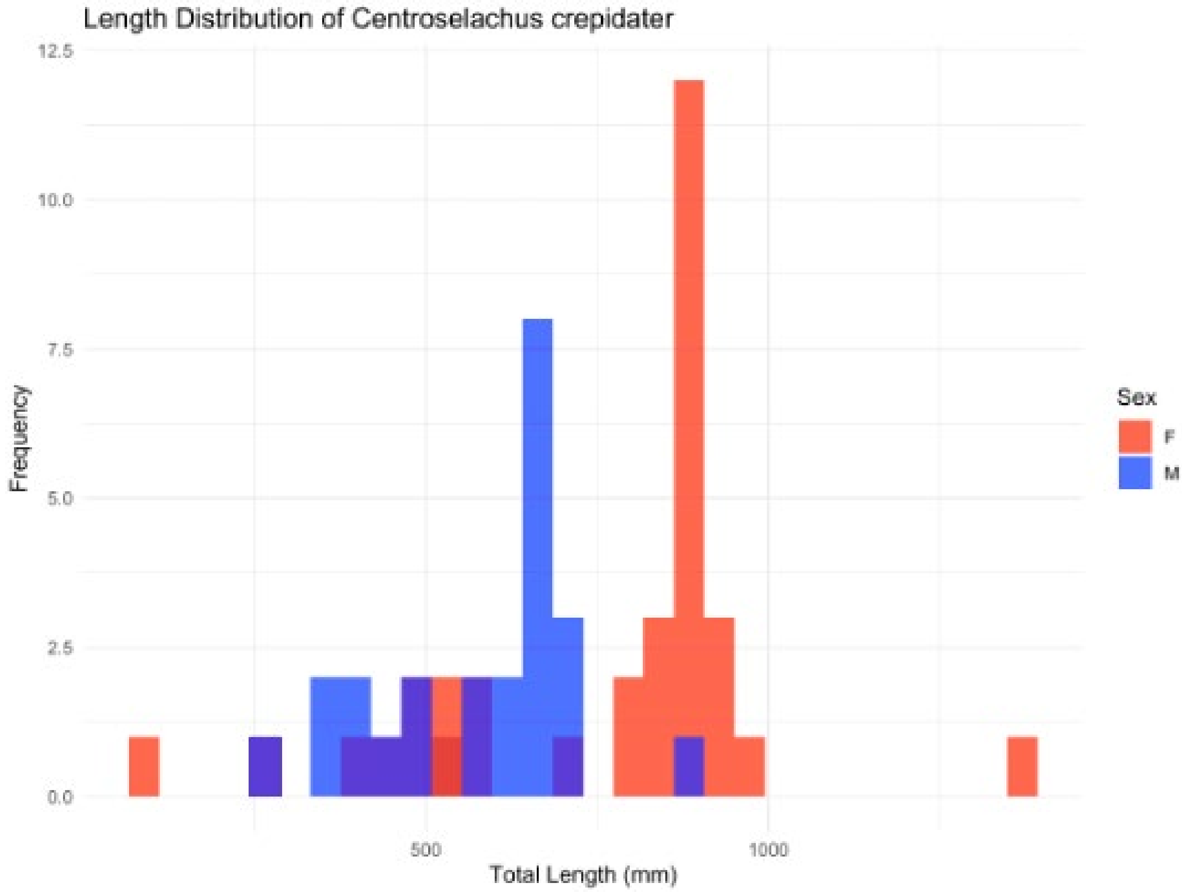


Figure 30. *Centroselachus crepidater* size distribution of males (blue) and females (red) from the 2024 survey

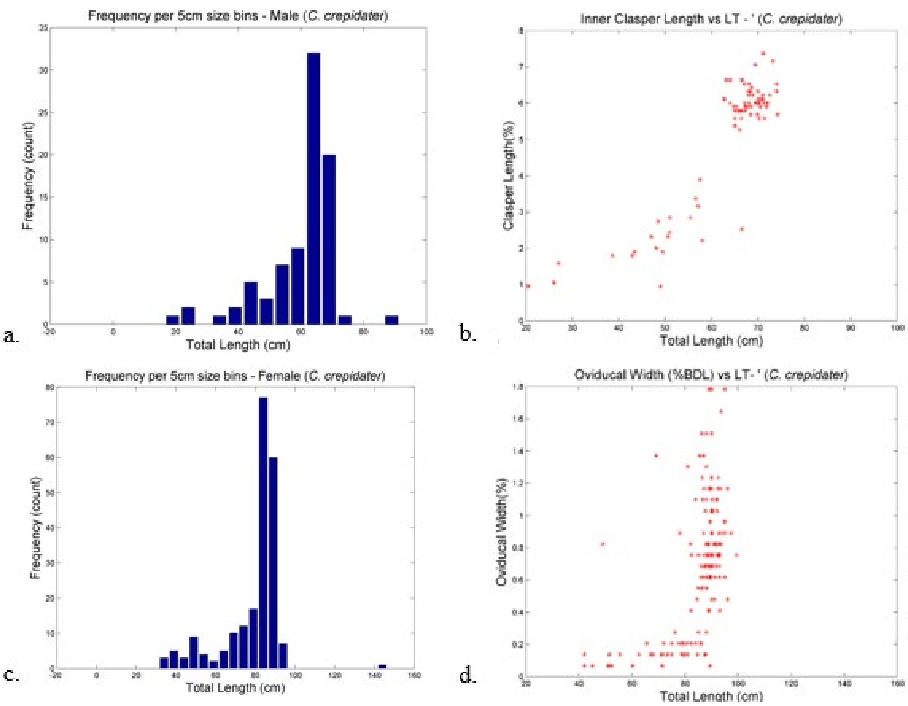


Figure 31 *Centroselachus crepidater*: a) size distribution of males, b) relationship between inner clasper length (%LT) and LT (males), c) size distribution of females, and d) relationship between shell gland width (%LT) and LT (females) from the 2012 and 2014 surveys.

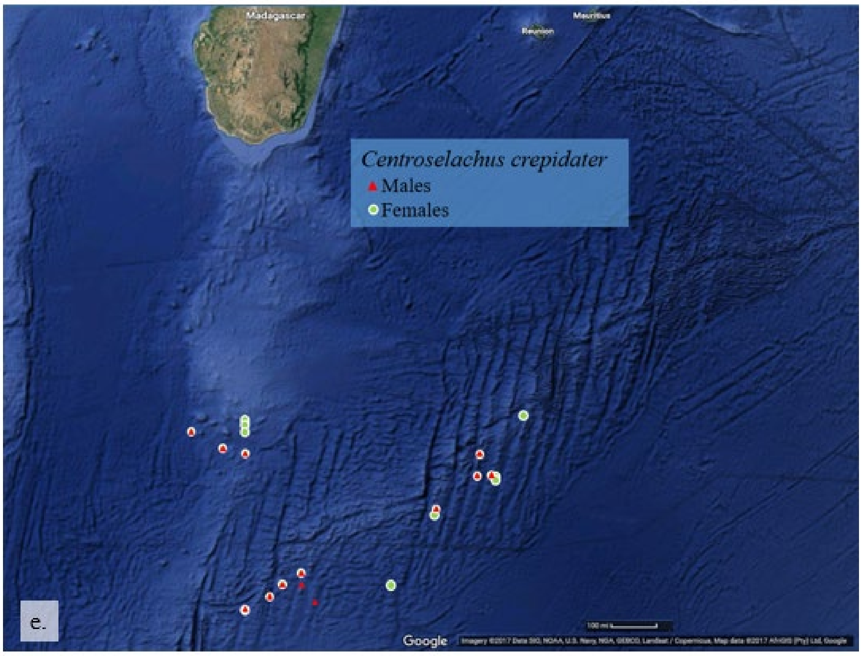


Figure 31 *Centroselachus crepidater* distribution of males (red triangles) and females (green circles) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

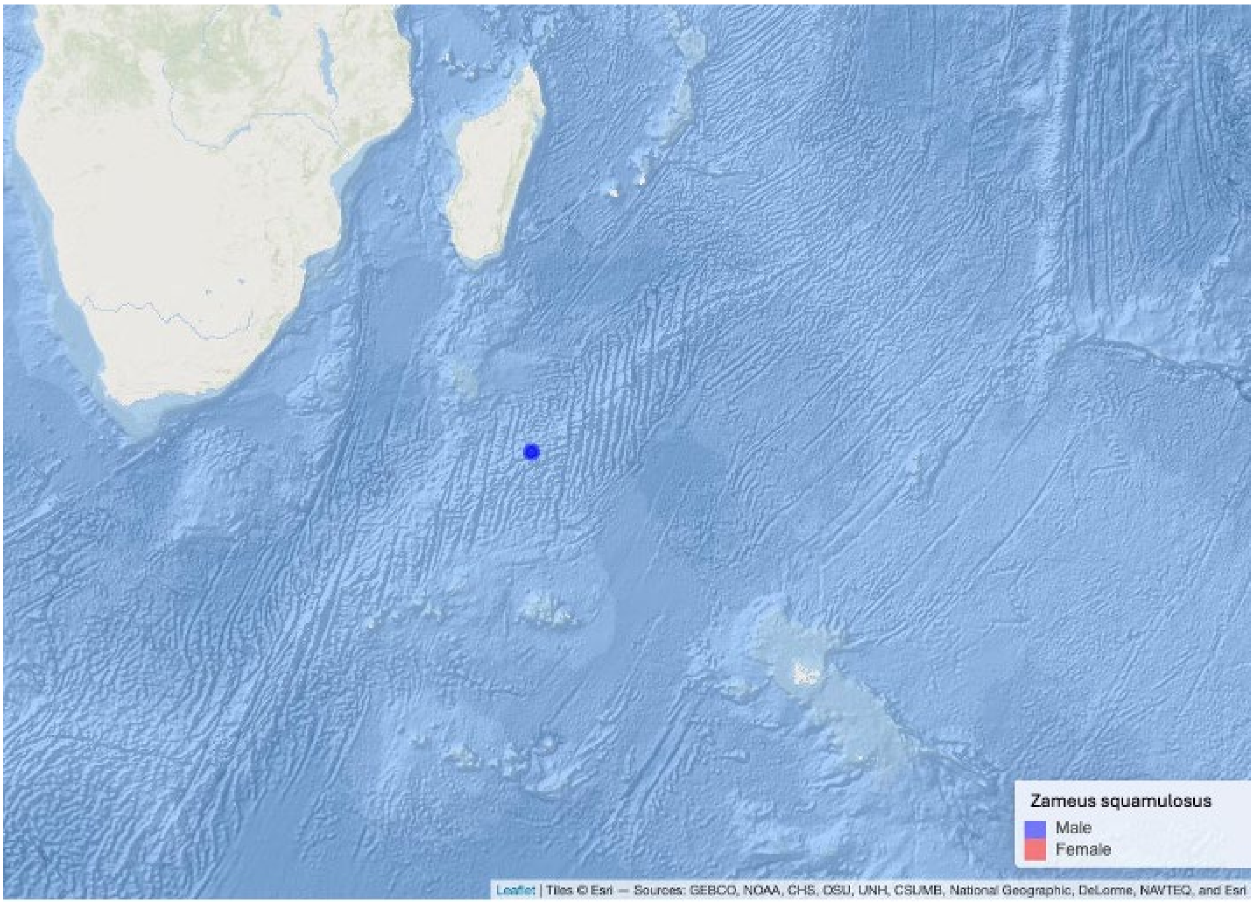


Figure 32. Distribution of *Zameus squamulosus* male encountered during the 2024 survey

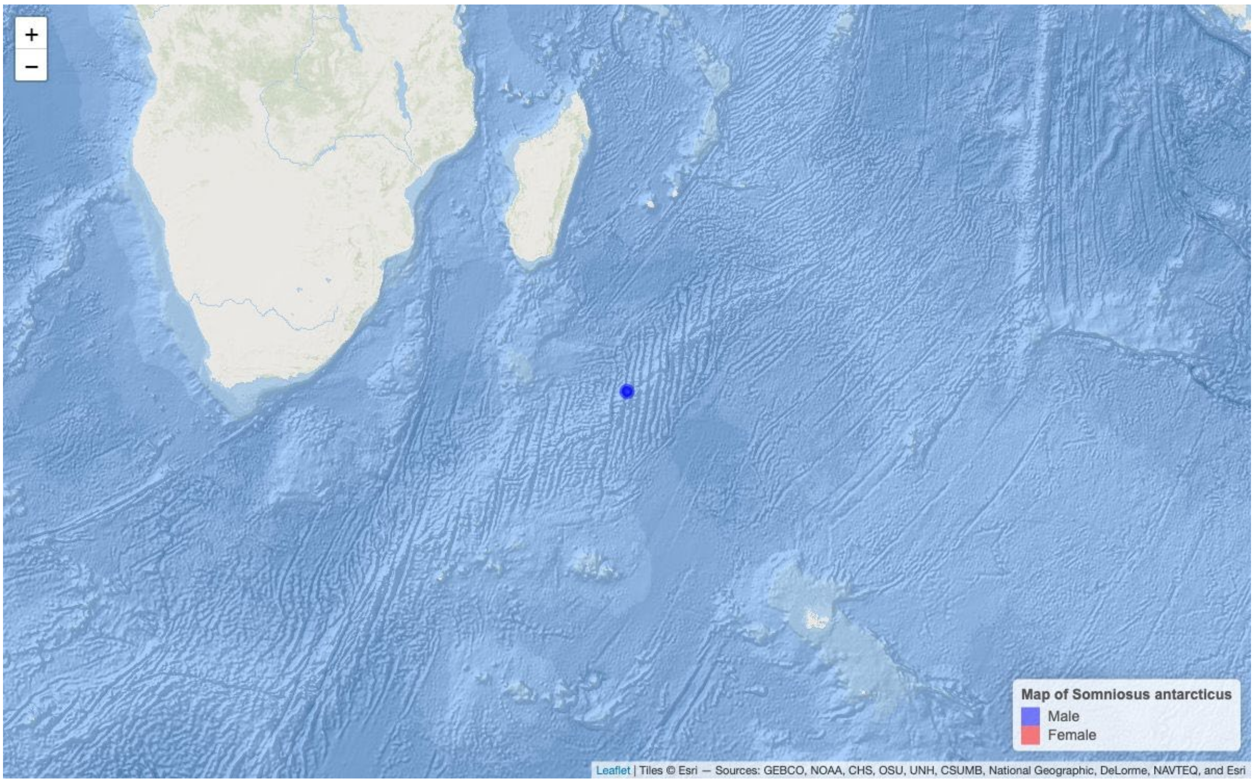


Figure 33. Distribution of *Somniosus antarcticus* male encountered during the 2024 survey

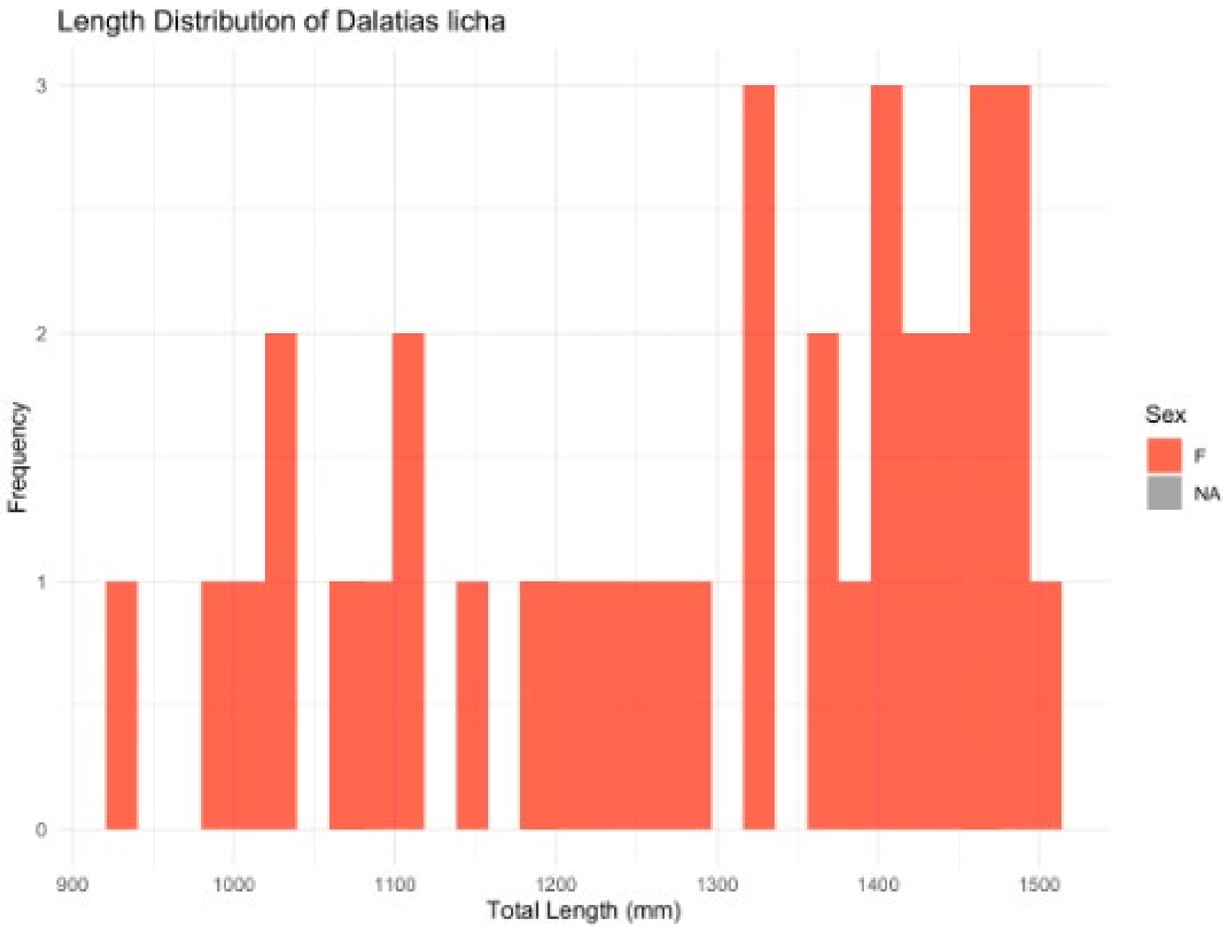


Figure 34 *Dalatias licha* size distribution of females from the 2024 survey

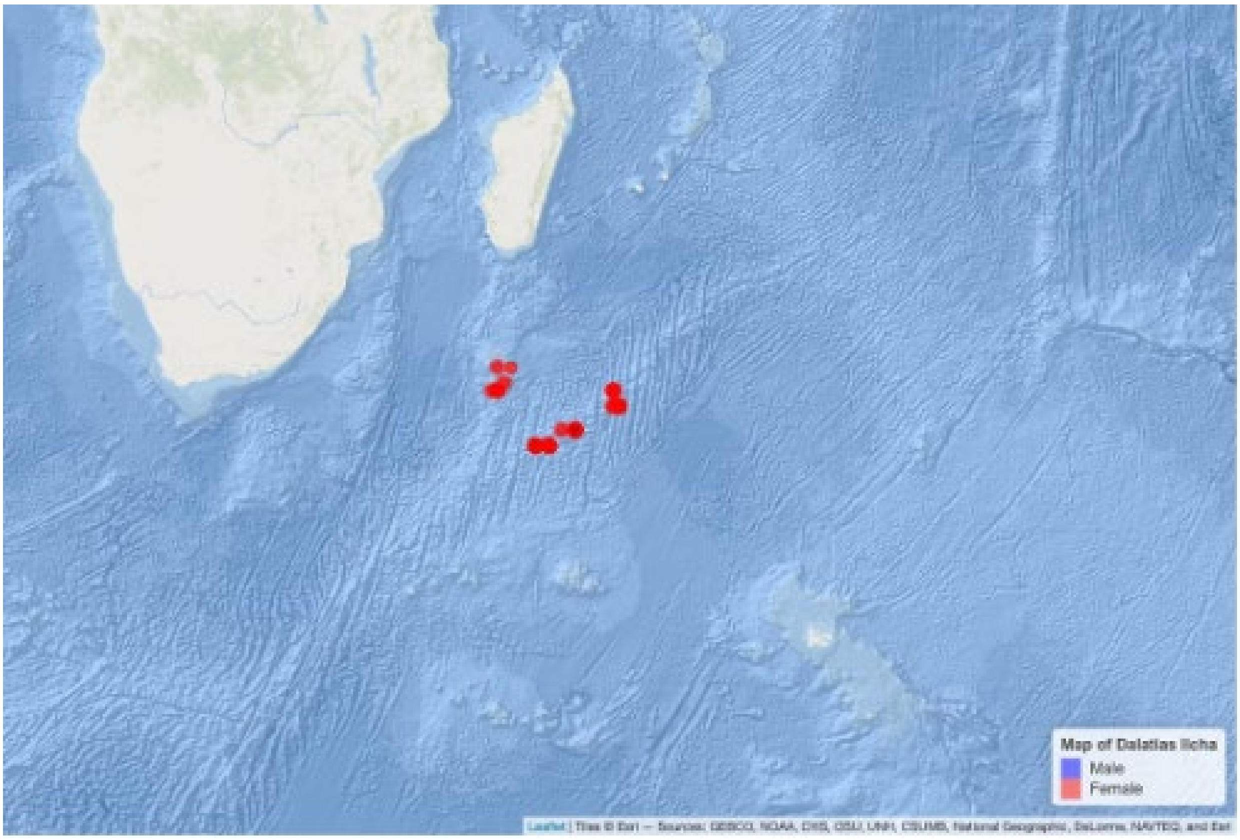


Figure 35. Distribution of *Dalatias licha* females encountered during the 2024 survey

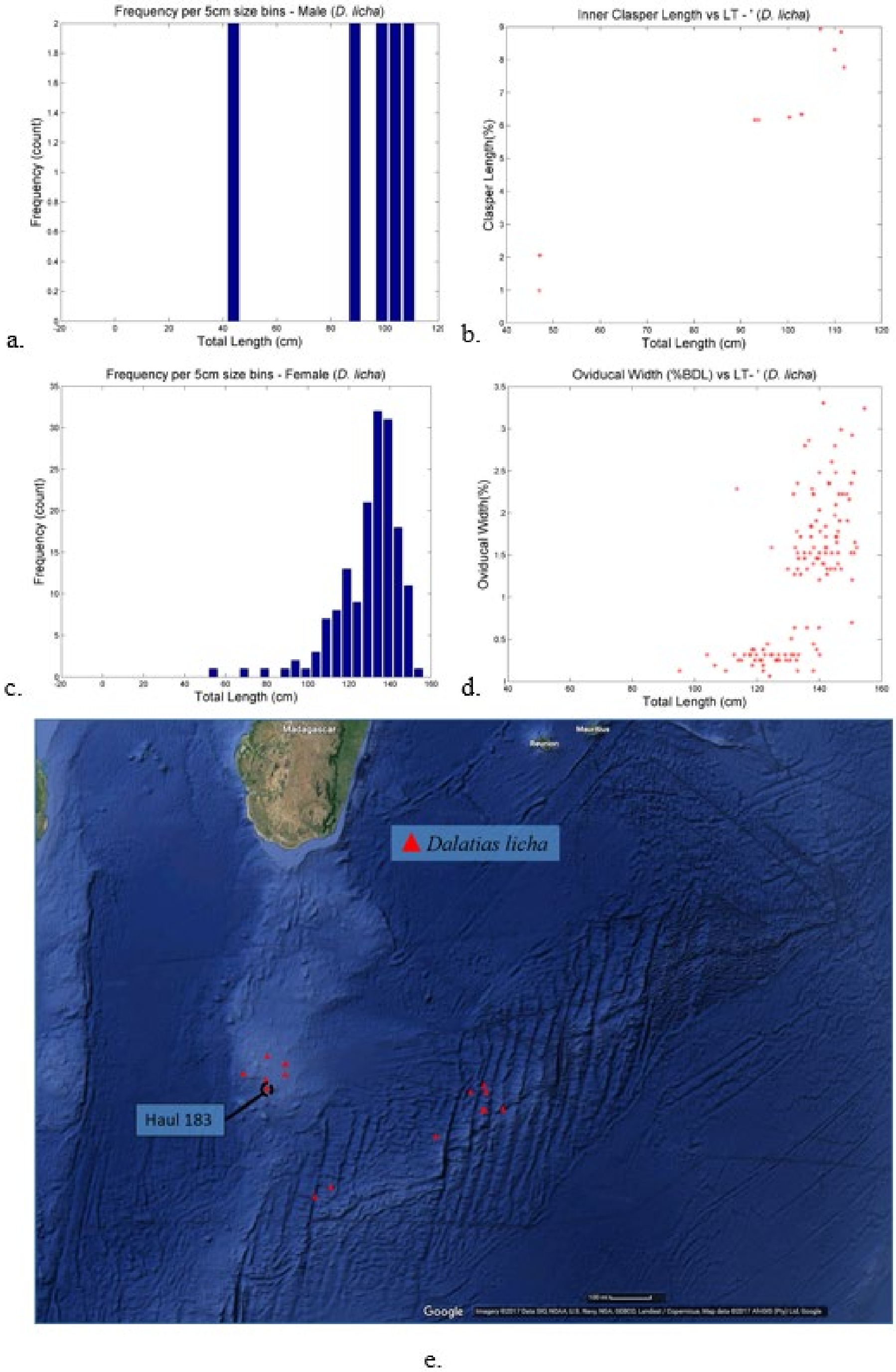


Figure 36. *Dalatias licha*: a) size distribution of males, b) relationship between inner clasper length (%LT) and LT (males), c) size distribution of females, d) relationship between shell gland width (%LT) and LT (females), and e) distribution (red triangles) and Haul 183 (indicated) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

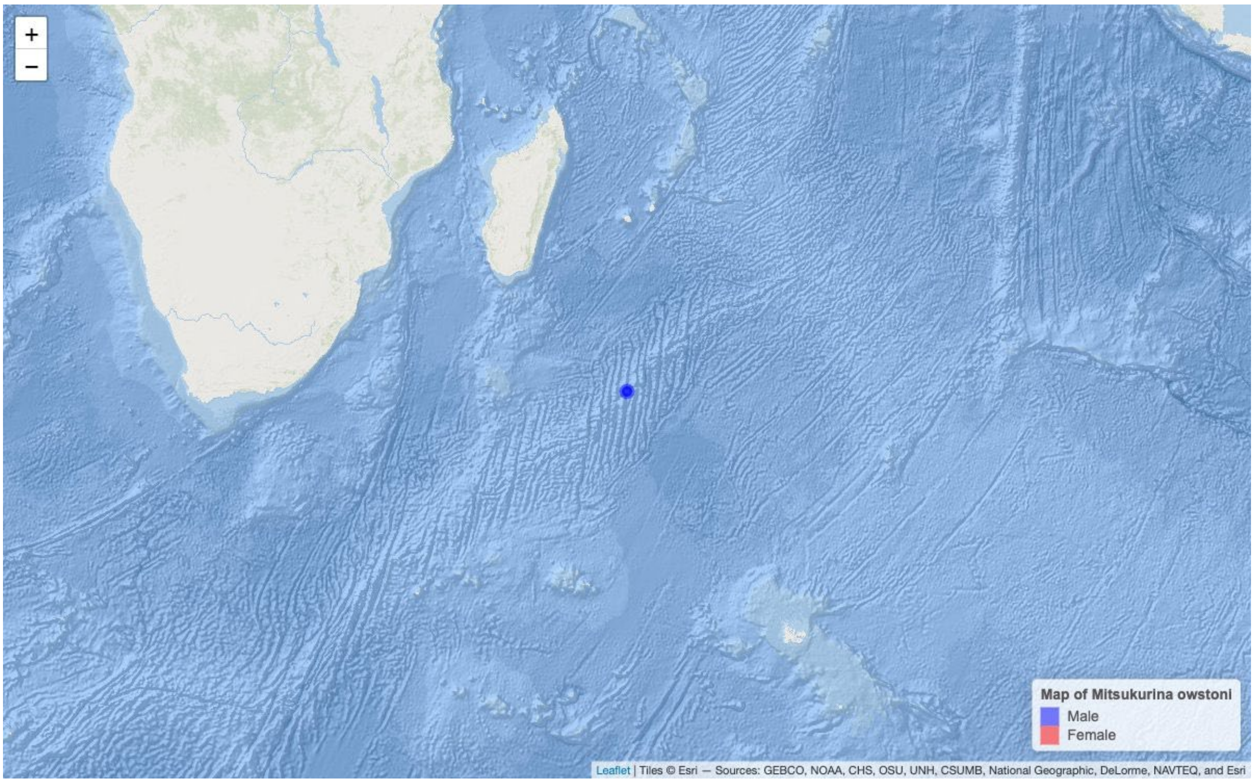


Figure 37. Location of *Mitsukurina owstoni* male encountered during the 2024 survey

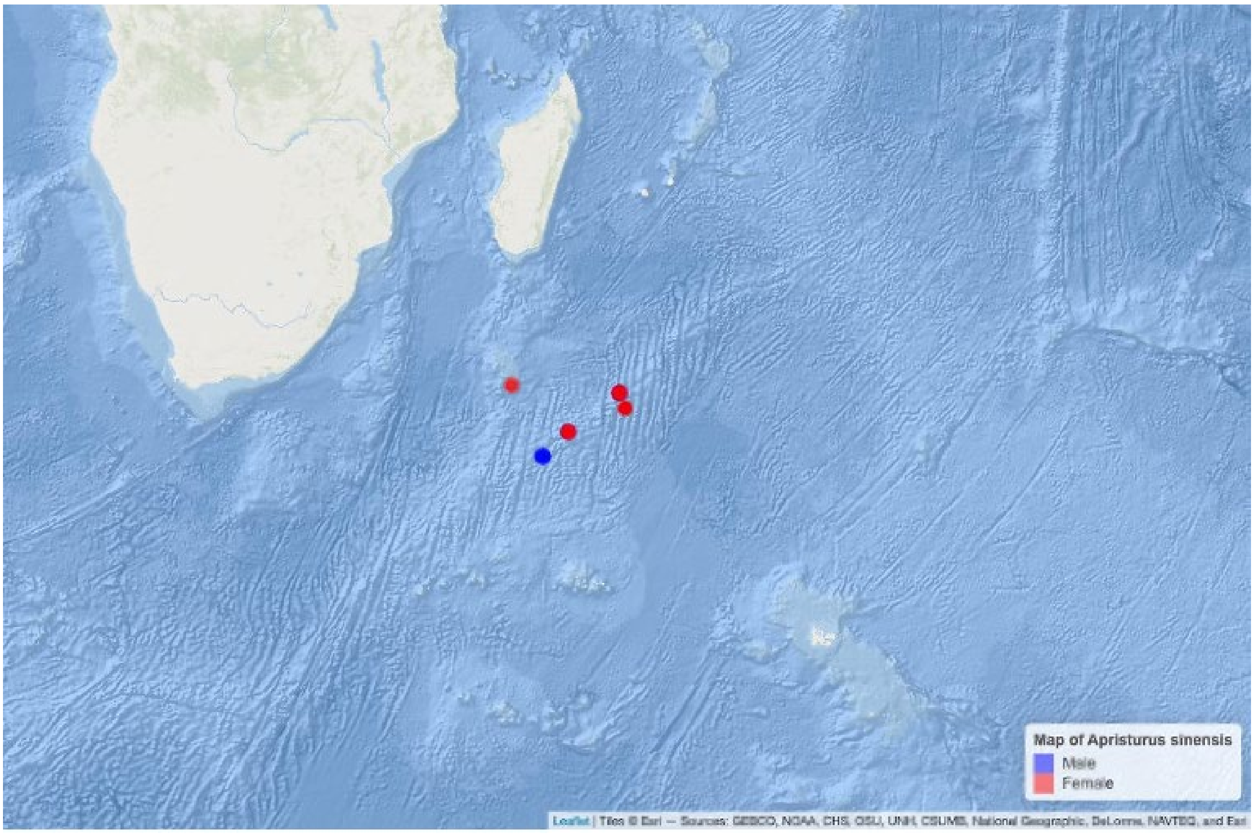


Figure 38. Location of *Apristurus sinensis* males (blue) and females (red) encountered during the 2024 survey

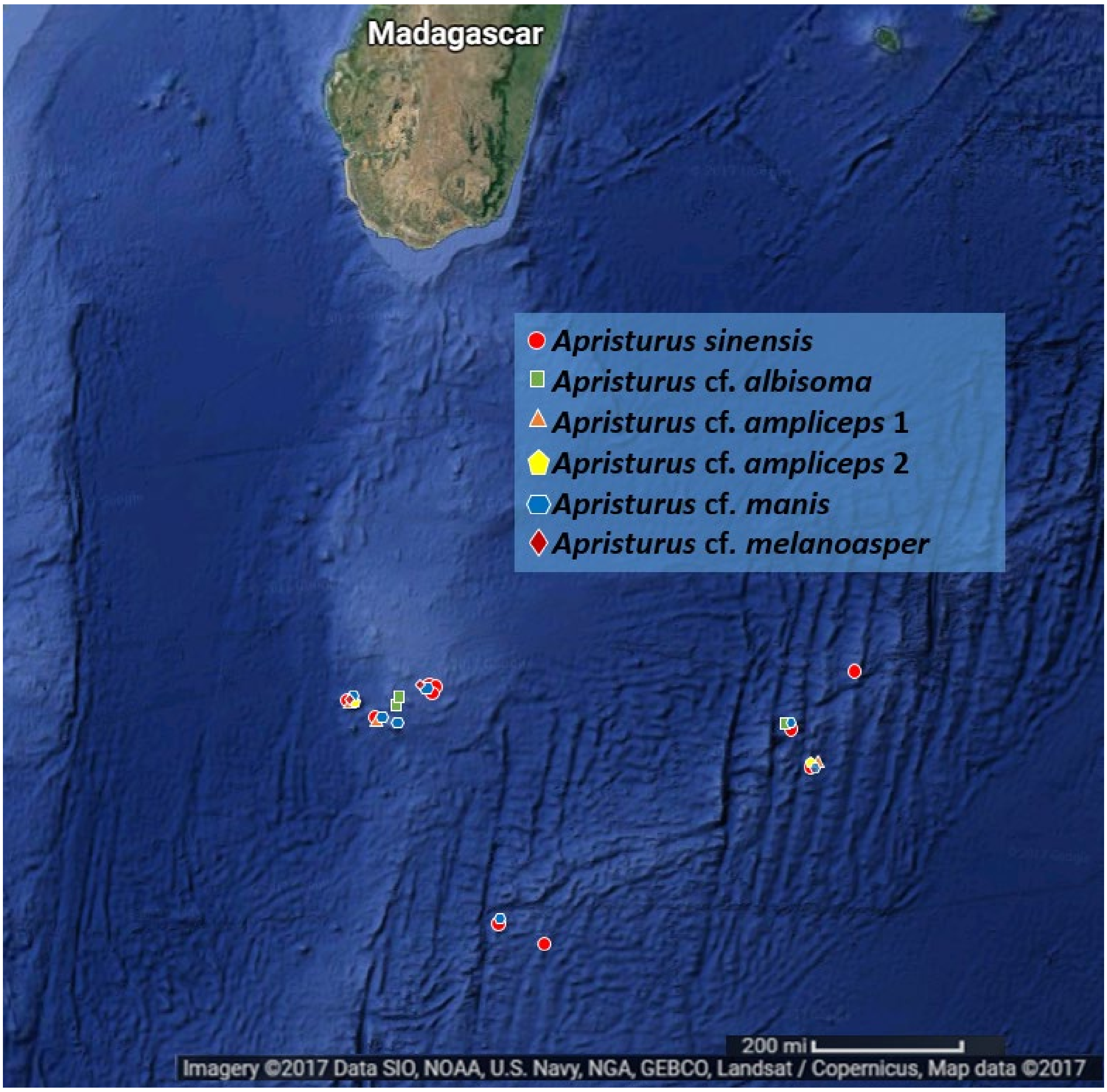


Figure 39. Distribution of the genus *Apristurus*: *A. sinensis* (red circle), *A. manocheri* (green square), *A.* cf. *ampliceps* 1 (orange triangle), *A.* cf. *ampliceps* 2 (yellow pentagon), *A.* cf. *manis* (blue hexagon), and *A.* cf. *melanoasper* (maroon diamond) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.

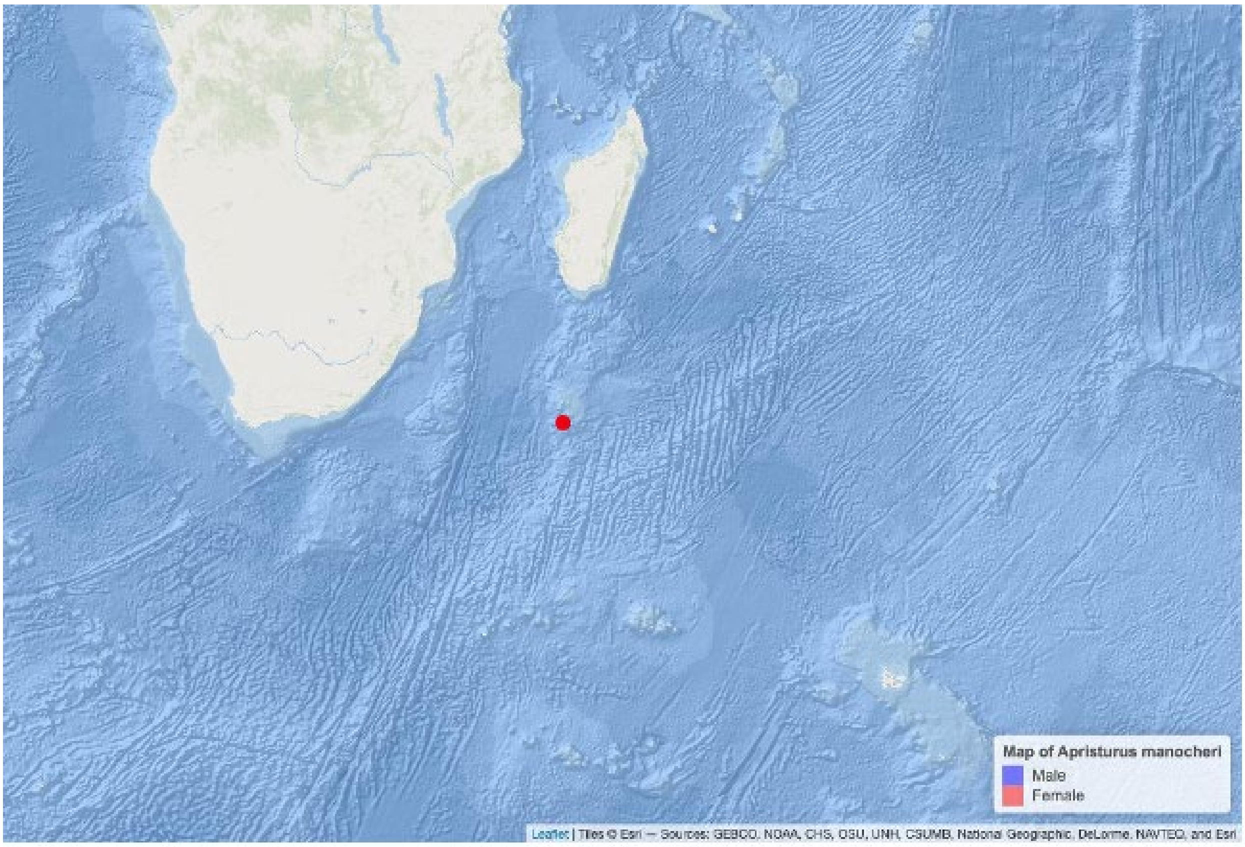


Figure 40. Location of *Apristurus manocheri* male encountered during the 2024 survey

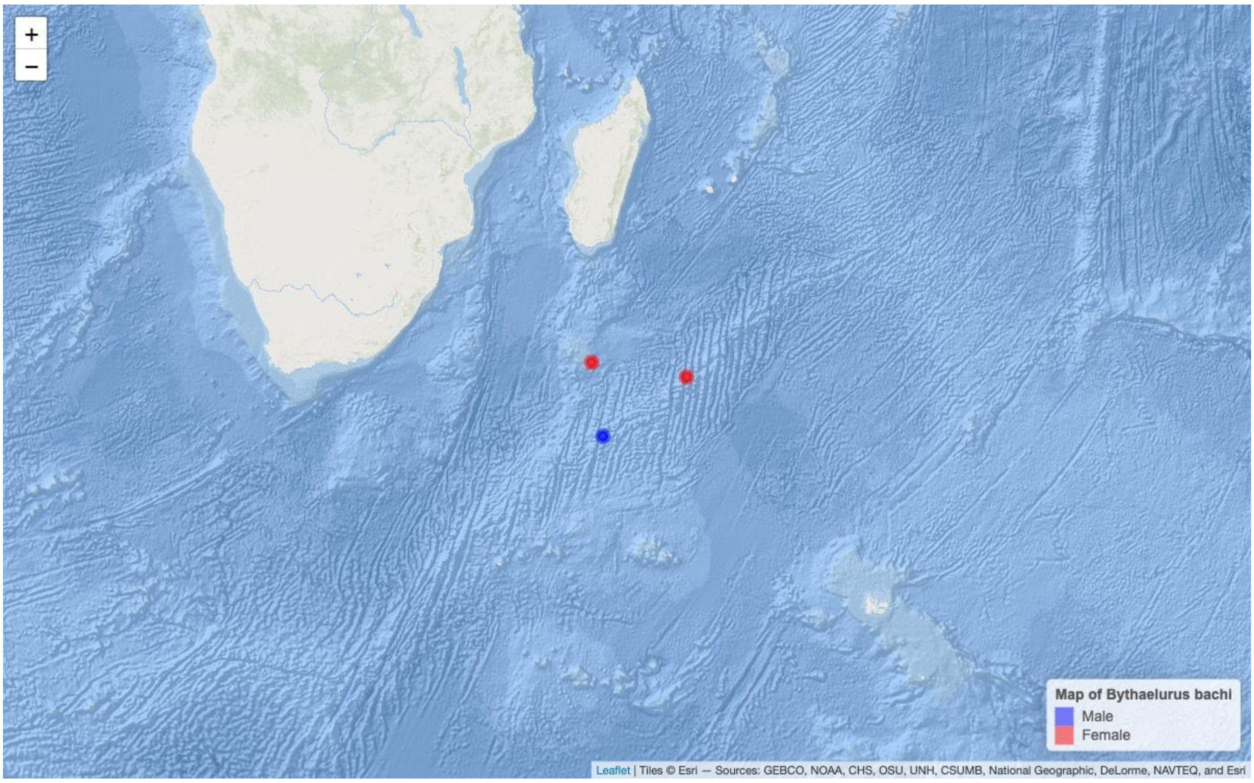


Figure 41. Location of *Bythaelurus bachi* male (blue) and females (red) encountered during the 2024 survey

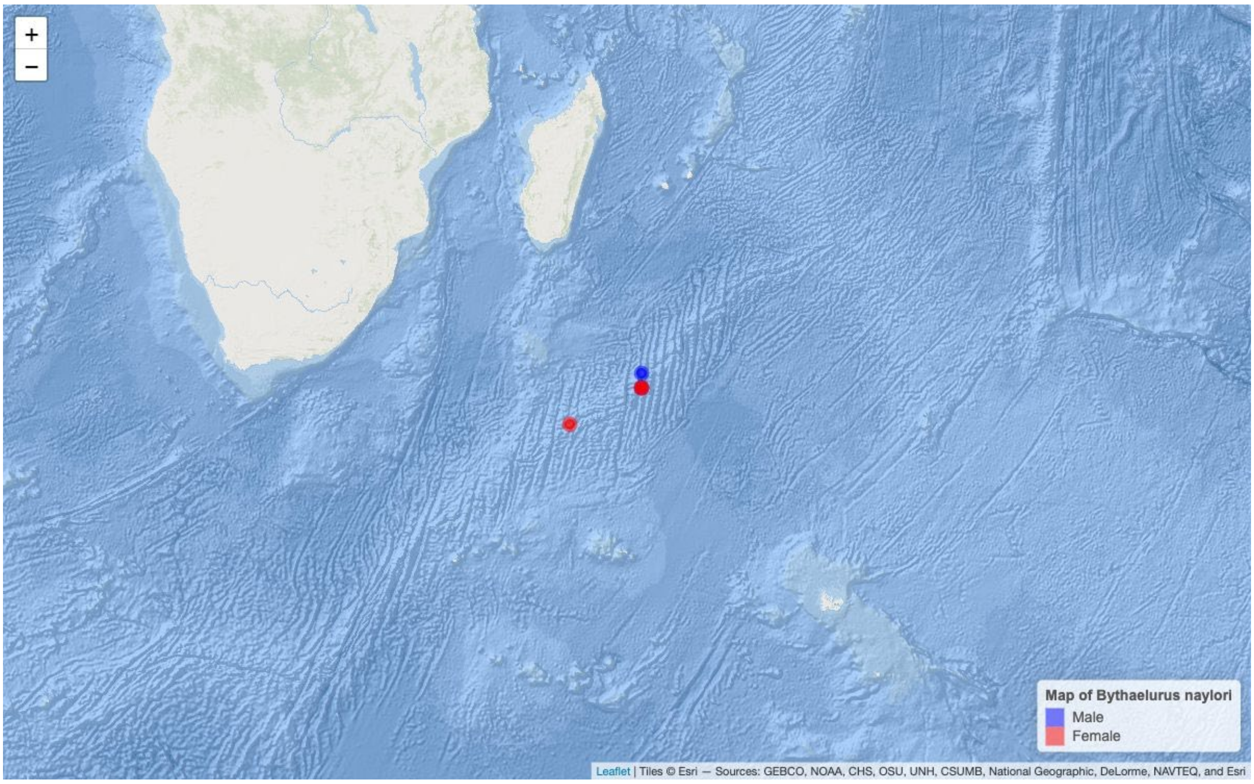


Figure 42. Location of *Bythaelurus bachi* male (blue) and females (red) encountered during the 2024 survey

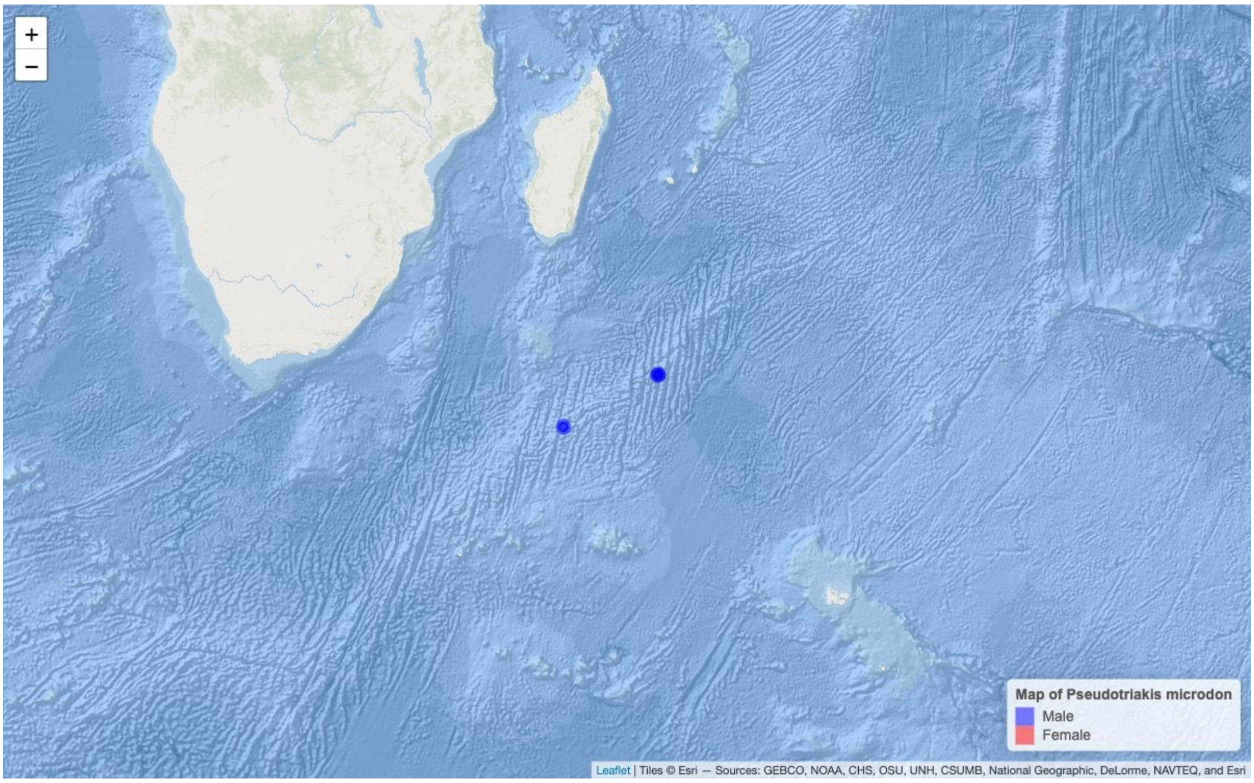


Figure 43. Location *Pseudotriakis microdon* males encountered during the 2024 survey

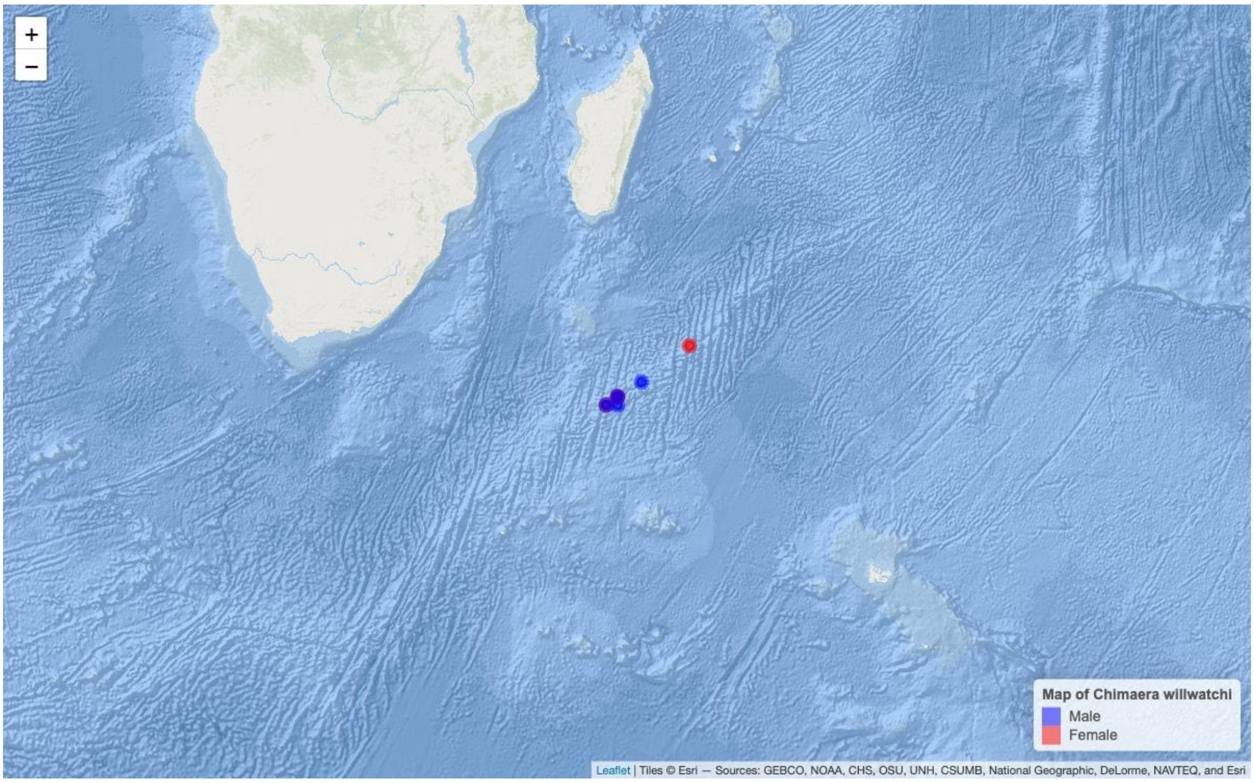


Figure 44 Location of *Chimaera willwatchi* male (blue) and females (red) encountered during the 2024 survey

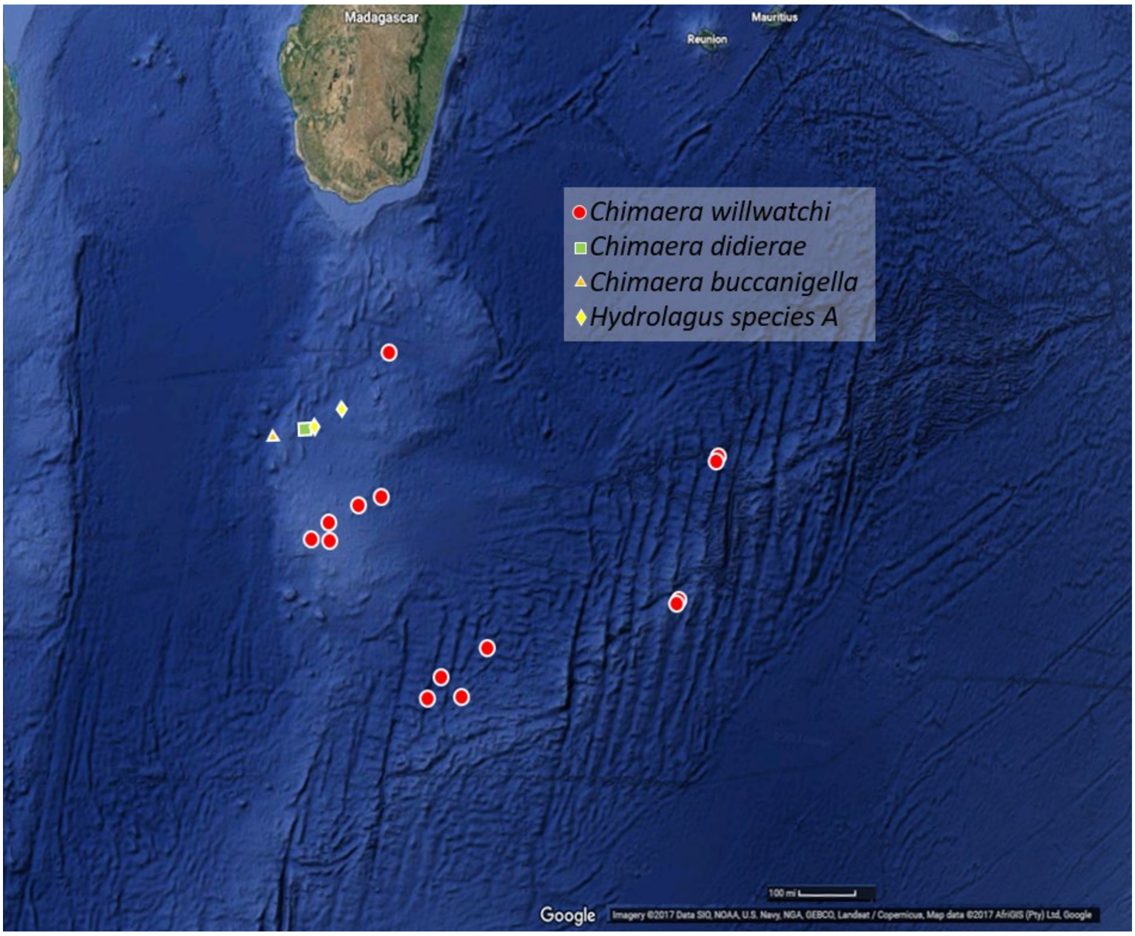
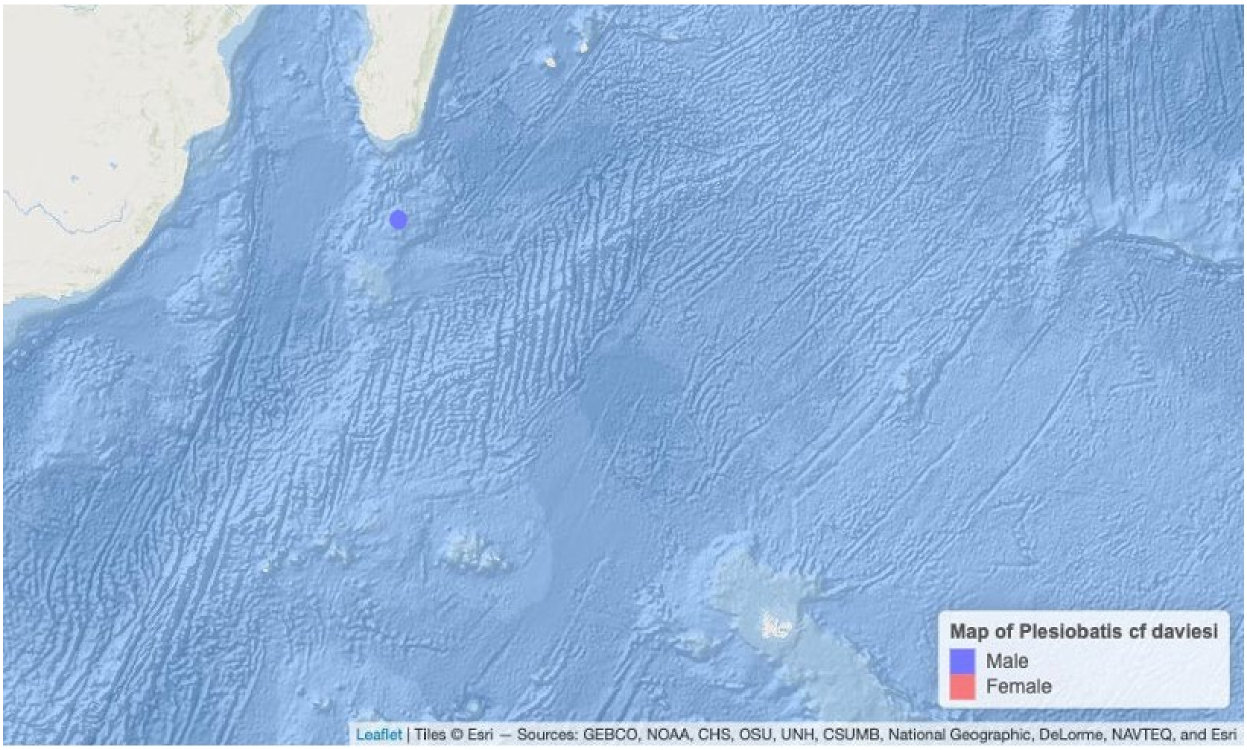


Figure 45. Distribution of *Chimaera* encountered: *Chimaera willwatchi* (red circles), *Chimaera didierae* (green square), *Chimaera buccanigella* (orange triangle), *Hydrolagus* species A (yellow diamond) encountered during the 2012 and 2014 surveys. Map data: Google, Image © 2017 DigitalGlobe.



Location of *Plesiobatis* cf *daviesi* male encountered during the 2024 survey

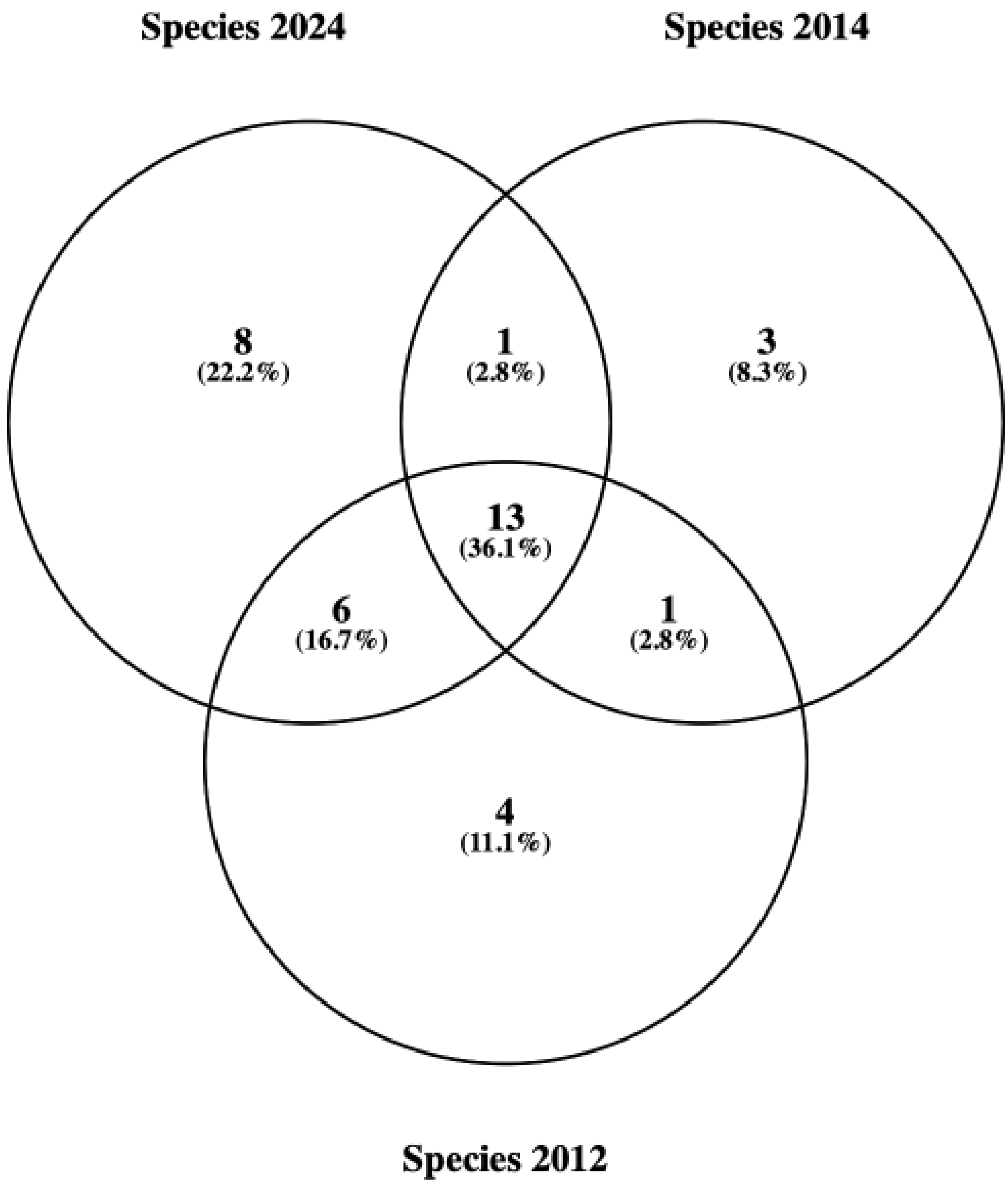


Figure 47. Venn diagram showing overlap of species encountered during 2012, 2014, and 2024 surveys

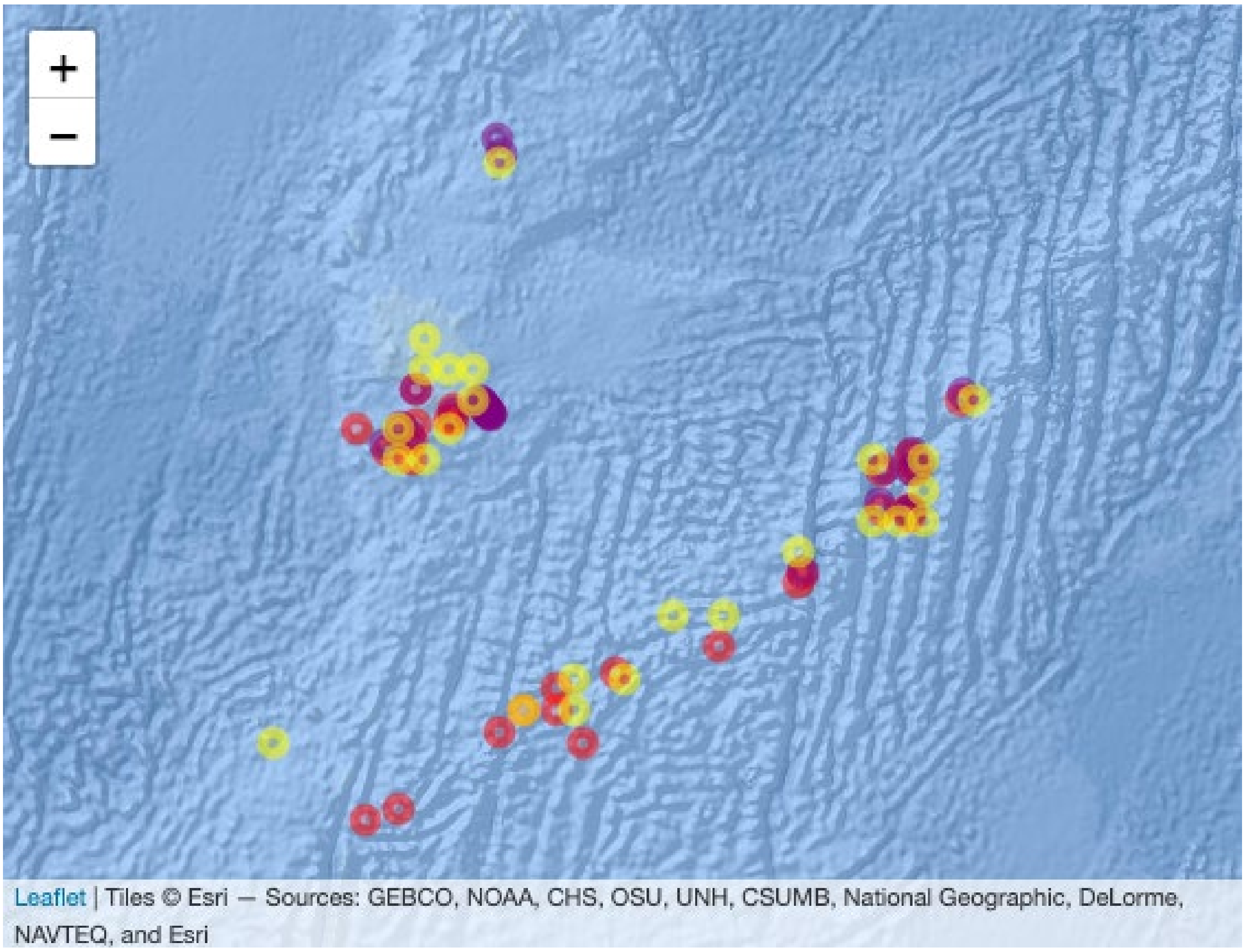


Figure 48. Locations fished during three surveys from 2012 (red), 2014 (purple), and 2024 (yellow).