Chapter 7

Demersal resources based on bottom trawl and other sampling methods

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"The *Nansen* has accumulated large amounts of valuable information on seafloor conditions and fish resources."

Abstract

The RV *Dr Fridtjof Nansen* has accumulated large amounts of valuable information on seafloor conditions and fish resources, based mainly on bottom trawling and acoustic recordings. In some regions, these data are the only information that exist. Over 1 500 trawls have been completed, mostly (68 percent) on the shelf (<200 m depth). Rocky or steep areas that could not be trawled have, in some cases, been sampled with baited traps and hook-and-line methods. Despite the unbalanced distribution of surveys over time and space, broad patterns in fish distribution and densities are apparent. Pelagic taxa such as scads (Carangidae) and sardinella (Clupeidae) were often abundant in demersal trawls, and these taxa were included in the analyses. Fish densities were relatively higher in the Somali Coast subregion than elsewhere, and also higher on the shelf than on the slope, between 200 and 800 m depth. Densities of snappers (Lutjanidae) were consistent across shelf subregions, particularly after 2007, whereas seabreams (Sparidae) exhibited a subequatorial distribution, occurring in Somalia in the north, and in southern Mozambique/southern Madagascar, but not in-between. Crustaceans predominated on the Mozambique shelf, consistent with the information from prawn trawl fisheries. Estimates produced from *Nansen* surveys are not dissimilar to those produced by other surveys in the Western Indian Ocean. The consistency of the *Nansen's* sampling approach over the years means that valid spatio-temporal comparisons of catch composition, catch rates and size frequencies can be undertaken, to build on the broad overview presented here. Overall, *Nansen* surveys reflect a high diversity of demersal fauna, but apart from prawns and deep-water crustaceans, found only limited fisheries potential on the generally narrow shelf and upper continental slope. The concentration of the main demersal fisheries where there is riverine input suggests that terrestrial nutrient sources are of greater importance than upwelled nutrient sources for demersal species in Kenya, Tanzania, Mozambique and Madagascar. In Somalia, where there are few rivers, upwelled nutrients give rise to high productivity, and greater demersal fish densities than further to the south. The recent focus on wider ecosystem aspects of demersal habitats using non-trawl methods holds promise, even though sampling protocols are still being developed.

Previous page: *Chaunax atimovatae* from ACEP ROV off Thukela. © DST/NRF ACEP Spatial Solutions Project

7.1 Introduction

Demersal species (fish and crustaceans) live and feed on the seafloor, which usually consists of mud, sand, gravel or rocks. Demersal fish are either benthic (rest on the seafloor) or bentho-pelagic (float in the water column just above the seafloor). Most demersal fish species are bentho-pelagic, and all of them are bottom-feeders, inhabiting the continental shelf of coastal waters, and the upper part of the continental slope. They are also found on seamounts and around islands, but are uncommon in the deepest waters, such as the abyssal plains.

Demersal fish have many different body types, many of them flattened in one way or the other (for example flatfish, skates and rays), or in the case of bentho-pelagic species, they often have a flabby body type with large head and reduced body size (such as rattails and cusk-eels) or they can be robust and muscular swimmers (such as squaloid sharks or orange roughy). Crustaceans that live on the seafloor include many groups that are important to commercial fisheries, because of their high unit value, for instance, lobsters, prawns and crabs.

The initial focus of the RV *Dr Fridtjof Nansen* surveys in the Western Indian Ocean was on assessing fisheries potential, particularly of pelagic fishes, using the acoustic method for biomass estimation (Chapter 6). Over the years, using bottom trawling and the "swept area" method to estimate the biomass of demersal fisheries resources near the seabed also became important. However, these demersal trawl surveys could only cover trawlable sandy or muddy grounds; consequently fish or crustaceans living on coral reefs or rocky outcrops could not be sampled. More recently, technologically advanced acoustic methods have been used to assess demersal fish in untrawlable areas. Static sampling methods, such as hook-and-line fishing and setting baited traps have also occasionally been used to sample untrawlable areas, but these methods are time-consuming and require many replicates before confident conclusions can be drawn.

Pelagic fish (see Chapter 6) are frequently caught in bottom trawls, together with demersal species, presumably because they school low down in the water column at certain times. The approach taken in Chapter 7 was to include all catches made by bottom trawl gear (demersal and pelagic species) in the analyses. This differs from the approach taken in Chapter 6, which dealt only with the pelagic component of trawl catches.

Trawl catches were also used to collect biological data of common fish and crustacean species, including their size structure, gender and reproductive condition. *Nansen* surveys in Mozambique focussed mainly on assessing shallow- and deep-water prawn resources. Recent surveys have incorporated sampling to characterize macrobenthos (small invertebrates associated with the seafloor) and to assess pollutants in sediments, as part of the increasing focus on ecosystem considerations (Chapter 2). These data can be used to establish environmental baselines prior to the commencement of oil and gas operations in the Western Indian Ocean. Acoustic scanning is used during all surveys to map the seabed while steaming between trawl stations, as a means of identifying trawlable areas. Chapter 7 reviews the demersal activities of the *Nansen*, including bottom trawling, acoustic recordings, trap and hook-and-line sampling, benthic sediment grabs and seabed mapping.

7.2 General sampling and analysis

The trawl gear used by the *Nansen* includes trawl warps, winches, a bottom (demersal) trawl which is retrieved onto a net drum, and combination trawl doors (see Appendix 7.1 for details on trawl gear, sampling protocols and analyses). Most trawling occurred on the continental shelf (20–200 m depth) and the upper continental slope (200–800 m depth), with sampling stations situated along transects perpendicular to the coast. Trawls were only deployed after ensuring that the seafloor was trawlable, based on evaluation of echo-soundings recorded while steaming over the area. Apart from the surveys in Somalia and Mozambique before 1980, where bottom trawl sites were chosen on the basis of acoustic signal strength – indicating dense fish concentrations – trawl stations were chosen to cover as much of the shelf as possible, within the time available for the survey. Trawls lasted for 30 minutes, or shorter if the seafloor was unsuitable, and most trawls were undertaken in daytime to reduce bias in catches, caused by demersal fish rising up off the seafloor at night.

Catches were processed on deck, and were sub-sampled if there were too many fish to count or measure. Catch weight, number of fish and species composition were recorded as well as biological data of common species. For analysis, fish families and species that contributed most to trawl catches, by weight and number, were compared between the six subregions, the two main survey periods defined in Chapter 3, and between the shelf (20–200 m depth) and upper slope (200–800 m depth) habitats.

We also calculated densities of fish and crustaceans based on the area "swept" by the trawl net. In other words, using the speed of the ship, the width of the trawl opening and the time spent by the trawl on the seabed, we calculated the area covered by each trawl when fishing. The weight of the catch made by the trawl was then divided by this "swept area" to obtain densities in metric

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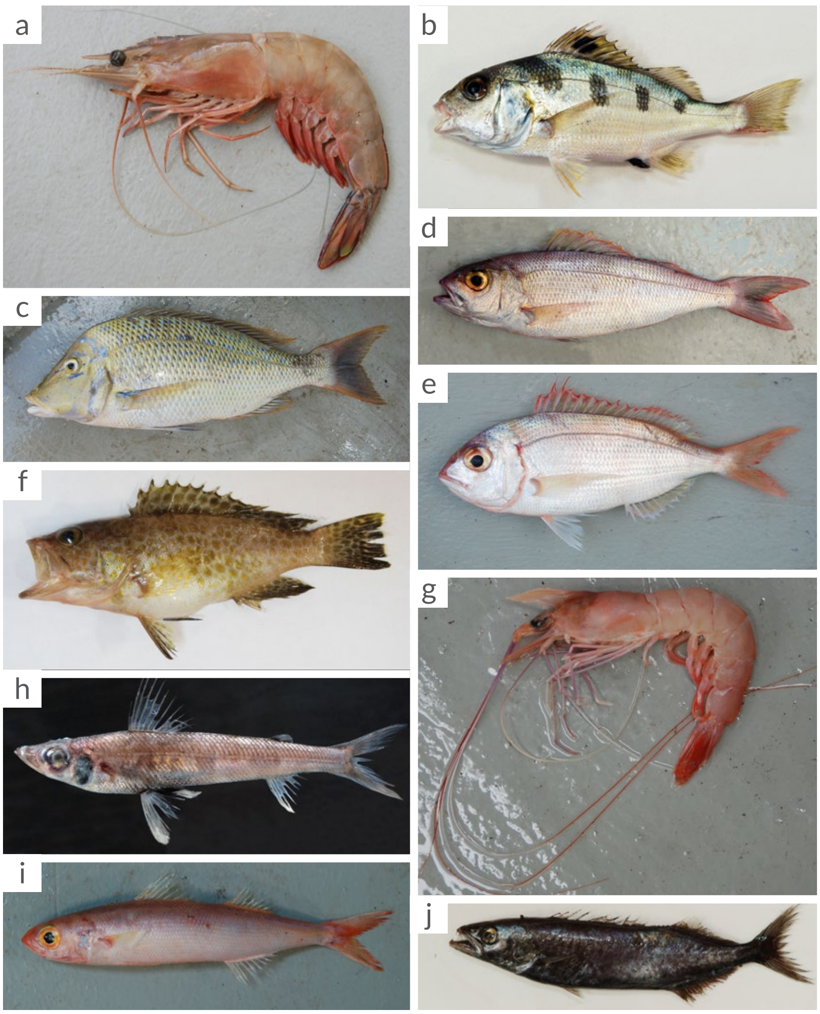

Figure 7.1 Representative species of demersal taxa with commercial value or potential commercial value examined in density plots. Shown as: Common name (Family, species name).

Continental shelf:

a. White prawn (Crustacea, *Penaeus indicus)*
b. Grunts (Haemulidae, *Pomadasys maculatum)*
c. Emperors (Lethrinidae, *Lethrinus nebulosus)*
d. Snappers (Lutjanidae, *Pristipomoides filamentosus)*
e. Seabreams (Sparidae, *Pagellus natalensis*)
f. Groupers (Serranidae, *Epinephelus areolatus*)

Upper slope:

g. Knife prawn (Crustacea, *Haliporoides triarthrus*)
h. Greeneyes (Chlorophthalmidae, *Chlorophthalmus punctatus*)
i. Rovers (Emmelichthyidae, *Emmelichthys nitidus*)
j. Snake-eels (Gempylidae, *Neopinnula orientalis*)

tonnes per square nautical mile (t/nm^2). For density estimates, we focussed on particular groups or families of demersal organisms because they have commercial value, or could potentially have commercial value in the future. On the shelf, these were: prawns, lobsters and crabs (Crustacea), grunts (Haemulidae), emperors (Lethrinidae), snappers (Lutjanidae), groupers (Serranidae) and seabreams (Sparidae). On the slope, the groups were Crustacea, green-eyes (Chlorophthalmidae), rovers (Emmelichthyidae) and snake-eels (Gempylidae) (Figure 7.1).

7.3 Bottom trawl surveys

The details of all demersal fishing methods used by the *Nansen* in the Western Indian Ocean are shown in Appendix 7.2. The timing of surveys over the past 40 years has been irregular, reflecting the vessel's busy schedule in different ocean basins (see Chapter 2), and also a lack of access to some areas of the Western Indian Ocean because of piracy threats. Trawling was the most common demersal sampling method, and the only one used for biomass and abundance estimation. Demersal sampling of deep slopes and seamounts in areas beyond national jurisdiction has been restricted to acoustic recordings or videography. We therefore present mainly the results of trawling, with limited descriptions of other sampling methods.

Surveys covered a wide geographical area, incorporating all countries in the Western Indian Ocean except South Africa (Figures 7.2 to 7.6). Over 1 500 trawls took place, of which 1 048 (68 percent) were deployed on the shelf (<200 m depth), and 481 (32 percent) on the upper slope (200–800 m depth). Two trawls occurred at depths >800 m, and depth was not recorded in two others. Most trawls were considered successful, with >91 percent of trawls having catches of 10 kg or more. Early surveys sampled as shallow as 10 m water depth, but the minimum trawl depth was later set at 20 m for safety reasons.

The highest catch recorded for an individual trawl was around 10 tonnes and the largest number of individual organisms estimated for a trawl was over 210 000. On average, catches were considerably lower than that, and highly variable (Table 7.1). A total of 309 families were recorded, of which 257 were teleosts (bony fishes) or elasmobranchs (sharks and rays). Some 229 families were identified from shelf trawls.

A total of 1 497 teleost and 158 elasmobranch taxa were identified to at least genus level, of which 75 percent of teleosts and 67 percent of elasmobranchs were caught in shelf trawls. These numbers indicate a high diversity, even in the absence of many reef-associated species, which were presumably under-sampled by trawl nets.

Table 7.1 General statistics on bottom trawls by the RV *Dr Fridjtof Nansen* in the Western Indian Ocean.

Maximum catch weight/trawl	~10 000 kg
Maximum catch numbers/trawl	>210 000
Mean catch weight/trawl (± SD)	160 (± 405) kg
Mean catch numbers/trawl (± SD)	4 594 (± 12 398)
Maximum taxa/trawl	71
Mean taxa/trawl (± SD)	21 (± 9)

The catches from bottom trawls were also used to collect biological information from commonly -occurring species and those prioritized in individual surveys. Two sets of biological information are available on Nansis; one comprising only length measurements, and the other, which is smaller, comprising lengths, weights, sex and maturity stages of a few species. Most length measurements were collected from prawns in Mozambique, reflecting the large number of surveys undertaken here, and the focus on commercially important crustaceans. A list of the length measurements and biological data collected per species on all surveys in the Western Indian Ocean is shown in Appendix 7.3.

Somali Coast subregion

Trawling on the narrow Somali shelf with its strong currents was considered difficult, and catches of demersal fishes may have been affected by the seasonal intrusion of low oxygen water onto the shelf during the Southwest monsoon (SW monsoon; see Chapter 4) (Bianchi, 1992). These low oxygen conditions may affect fish abundance and distribution patterns, through causing mortalities or migrations to areas with higher dissolved oxygen levels. We focussed on the 1970s surveys off the east coast (Sector 1 in Sætersdal *et al*., 1999) and Socotra (Sector 3). Some 103 trawls were undertaken on the shelf (mostly <100 m depth) and only nine on the slope. Few trawls were undertaken south of 2 °N (Figure 7.2), because the shelf becomes narrower to the south of that latitude, and initial estimates showed that biomass was concentrated further towards the north. Irregular bottom conditions around Socotra limited trawling areas. Results from the 1970s are summarized in Sætersdal *et al*. (1999) and Kesteven *et al*. (1981); the 1984 survey results are reported in Blindheim (1984) and Strømme (1984).

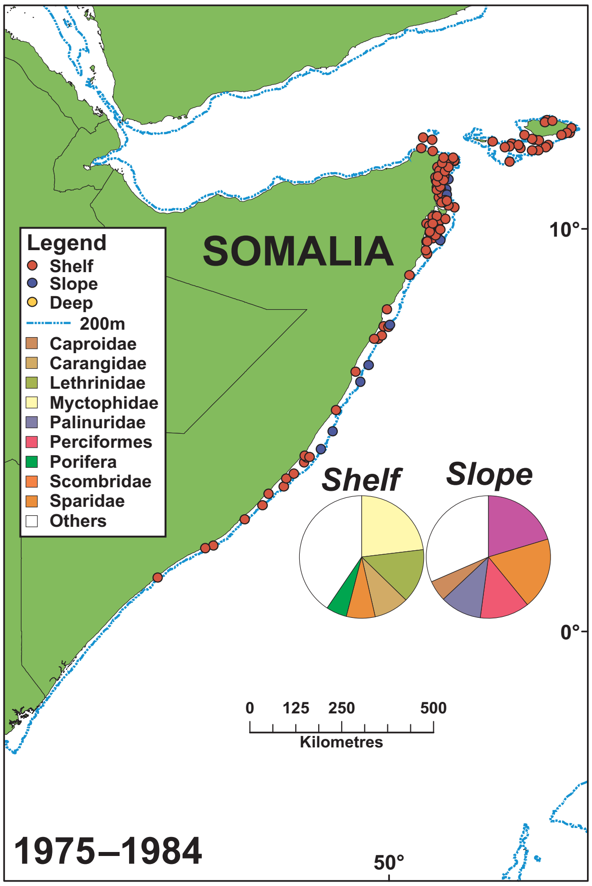

Figure 7.2 Bottom trawl sampling stations in the Somali Coast subregion, and catch composition (percentage by weight) by family or higher taxon.

The seasonal intrusion of low oxygen water onto the shelf associated with the SW monsoon (around August; Chapter 4) caused substantial changes in fish distribution (Bianchi, 1992; Sætersdal *et al*., 1999). For example, fishes normally considered to be associated with the seafloor, such as threadfin breams (Nemipteridae), catfishes (Ariidae) and ponyfishes (Leiognathidae), apparently moved higher up in the water column, adopting a more pelagic behaviour to avoid the low oxygen water along the bottom. Survey reports noted that distinguishing pelagic and demersal fishes (often an artificial distinction owing to the vertical migration habits of some species), was particularly difficult, with several families adopting semi-demersal habits. Because of the effects of the low oxygen water, it was felt that the trawl sampling of demersal fishes was probably positively biased towards true demersal species, which do not move higher into the water column at night, such as groupers, croakers, emperors and to a lesser extent, snappers (Sætersdal *et al*., 1999). Presumably this reasoning applied to the surveys around the SW monsoon months, or to particular sub-areas, as the bias towards true demersal fishes was not apparent from overall catch composition.

While some true demersal families such as Sparidae (seabreams) and Lethrinidae (emperors) were well represented, pelagic/mid-water families such as Myctophidae (lanternfish), Scombridae (mackerels), Carangidae (kingfish) and Clupeidae (sardines) were also prominent in bottom trawls on both the shelf and the slope (Figure 7.2). At genus level, the emperor *Lethrinus* contributed substantially on the shelf by weight, while *Pagellus*, *Decapterus* and *Etrumeus*, with smaller body size, were numerically prevalent. On the slope, *Pagellus* and *Scomber* contributed equally by weight and number, with high numbers of *Antigonia* (Appendix 7.4).

Other than the *Nansen* reports based on the 1970s and 1980s surveys, literature on the Somali Coast subregion is sparse. From the 1984 Northeast monsoon (NE monsoon) surveys, Bianchi (1992) reported two groupings of fishes, one associated with harder substrata (typically *Diagramma pictum*, *Epinephelus chlorostigma*, *Parupeneus pleurotenia* and *Lethrinus nebulosus*) and the other with softer substrata (*Decapterus russelli*, *Saurida undosquamis* and *Saurida tumbil*). In the SW monsoon survey in August 1984, during upwelling conditions, the hard-bottom indicator species were absent, and were replaced by *Cheimerius nufar*, *Diodon* spp. and cardinal fishes Apogonidae and sharks *Holohalaelurus* spp. The second group was characterized by *Saurida undosquamis* and *Pagellus affinis*. The seabream *Boops boops*, common in the Mediterranean and West Africa, was for the first time reported in the Western Indian Ocean (Bianchi, 1992). Persson *et al*. (2015) showed that Haemulidae (mainly *D. pictum*), Lethrinidae (particularly *L. nebulosus*), Serranidae (*Epinephelus* spp.) and Mullidae (*Parupeneus indicus*) were the most important demersal taxa in reconstructed industrial fisheries catches between 1950 and 2010. This result is in accordance with the observations made during the *Nansen* surveys in the Somali Coast subregion in the late 1970s and in 1984.

East Africa Coastal Current subregion (Kenya and Tanzania)

The surveys in Kenya covered trawlable areas between 10 and 500 m depth, but mostly between 20 and 200 m. Trawling focussed on the wide shelf in the central Malindi-Ungwana Bay area, with fewer trawls in the deep water south of Mombasa, and on the narrow steep slope of the North Kenya Bank (Figure 7.3) (Nakken, 1981; IMR, 1982a; Iversen, 1983). Results of trawl surveys are summarized in a special report of a NORAD-Kenya seminar on marine fish stocks and fisheries (Iversen, 1984; Iversen and Myklevoll, 1984).

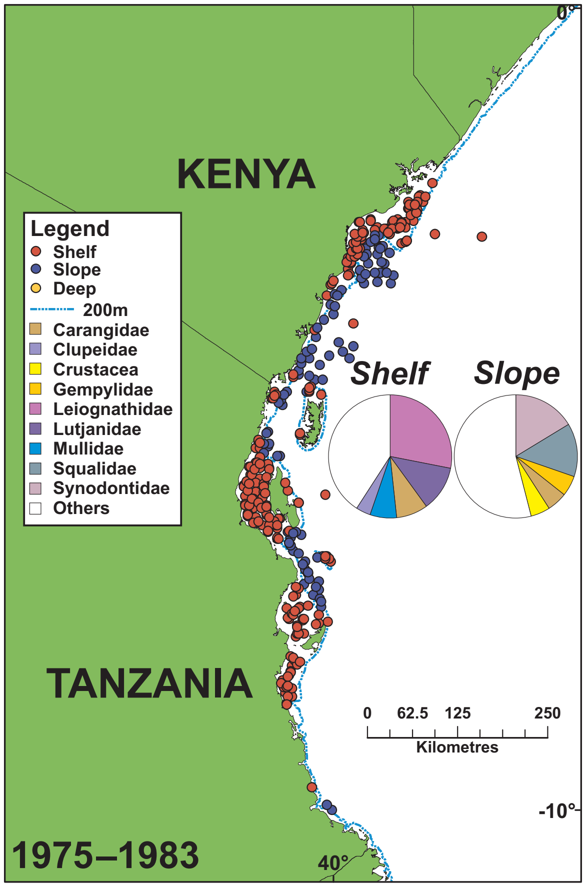

Figure 7.3 Bottom trawl sampling sites in the East Africa Coastal Current subregion, and catch composition (percentage by weight) by family; 10 trawls on the North Kenya Banks undertaken *en route* to doing Somali surveys in the 1970s are also included.

The trawl surveys in Tanzania covered the Zanzibar Channel and south to the Rufiji delta and near Mafia Island, because this area comprised almost 90 percent of the shelf and most of the trawlable substrate (Figure 7.3). Cruise reports (IMR, 1982b, 1983; Myklevoll, 1982) and a summary in a special report of a NORAD-Tanzania seminar describe survey details and results (IMR, 1983; Iversen and Myklevoll, 1984; Sætersdal *et al*., 1999).

Ponyfish (semi-demersal Leiognathidae of the genera *Leiognathus*, *Secutor* and *Gazza*) predominated by weight and number in shelf trawls, with Lutjanidae *Pristipomoides* contributing moderately (Figure 7.3 and Appendix 7.5). Pelagic taxa such as Carangidae *Decapterus* and Clupeidae *Sardinella* were also abundant in demersal trawls.

The predominance of Leiognathidae in shallow shelf waters, and presence of Haemulidae, Trichiuridae, Ariidae, Sciaenidae, Mullidae and Penaeidae (prawns) near river mouths has subsequently been confirmed by industrial trawl catches or other research surveys (Fennessy and Everett, 2015). Surveys in 2011 and 2012 for the Southwest Indian Ocean Fisheries Project (SWIOFP) found similar dominant shelf taxa in Kenya (Kaunda-Arara *et al*., 2016) to those reported by the *Nansen* in the early 1980s. In Tanzania, recent contributions of more valuable Haemulidae, Lutjanidae and Serranidae were lower than in the past, possibly a reflection of artisanal fishing effort in nearshore waters, with potential replacement by the more resilient Leiognathidae. The differences in trawled species composition between the early 1980s, and 2011 and 2012, require further investigation.

Deep-water sharks *Centrophorus* and *Dalatias* contributed by weight in slope trawls, with other noteworthy contributions coming from Synodontidae (lizardfishes, Saurida spp.) and crustaceans as an aggregated group. Numerically, the small-sized fishes of the Macrurocyttidae (dories, *Zenion*) and the Champsodontidae (gapers) predominated. In slope waters of 200 to 600 m depth, Everett *et al*. (2015a, b) reported numerical dominance of *Cholorophthalmus punctatus* and *Acropoma japonicum* off Kenya, and of *A. japonicum*, carid prawn *Heterocarpus calmani* and lizardfish *Saurida undosquamis* off Tanzania.

Mozambique subregion

The *Nansen* undertook 10 surveys in Mozambique waters between 1977 and 1990, and a further three between 2007 and 2014 (Appendix 7.2). The central zone of Mozambique (21°30'–17°15'S) includes the wide Sofala Bank, with valuable shallow-water prawn resources – most trawls were undertaken here, and on soft substrata in the southern zone to the South African border (Figure 7.4). Few trawls were undertaken north of 17°15'S because of a steep rocky seabed in this area. Surveys also investigated demersal

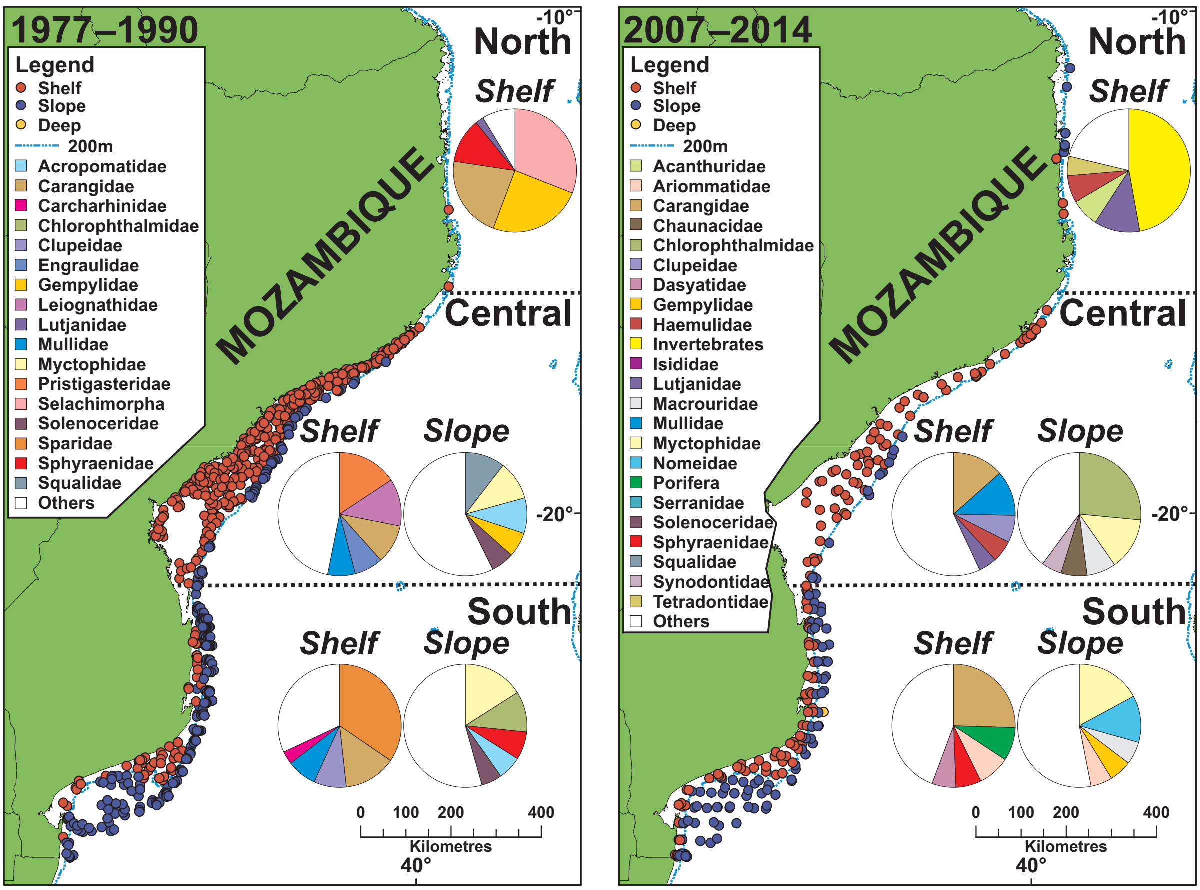

Figure 7.4 Bottom trawl sampling stations in three zones of the Mozambique subregion, and catch composition (percentage by weight) by family or higher taxon.

BOX 7.1

The RV *Dr Fridtjof Nansen* and prawn fisheries assessments in Mozambique

Shallow-water prawns (or shrimps) are caught by artisanal and industrial trawl fleets in Mozambique, and exports to the European Union and Asia made up 43 percent of foreign earnings from seafood in 2014 (Ministério das Pescas, 2015). The fishery started in the 1960s, and reached its zenith of nearly 10 000 tonnes per year in 2000/2001, whereafter landings declined to around 4 000 tonnes per year in recent times. The first *Nansen* survey to assess prawn stocks in 1980 covered the Sofala Bank (origin of 90 percent of shallow-water prawn catches) and Delagoa Bight. The surveys formed part of the Norwegian Aid Agency's long-term fisheries research and development support in Mozambique (Sætersdal *et al*., 1999). The *Nansen* surveys (total of 13 between 1977 and 2014) contribute to ongoing research and assessment of prawn resources, and also form the basis of scientific capacity building at the Intituto Nacional de Investigação Pesqueira (IIP) in Maputo. The prediction of catch rates based on pre-season assessments remains difficult, but annual surveys by different vessels (including the *Nansen*) provide information on inter-annual trends in prawn abundance.

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Penaeus spp. prawns from a shallow water prawn trawler.

Contributed by: Atanásio Brito
Intituto Nacional de Investigação Pesqueira (IIP), Mozambique

fish potential and deep-water crustaceans, and specialist studies in 2007 included detailed bottom mapping in selected areas and benthic grabs to establish baseline environmental conditions on offshore banks, protected areas, seamounts and areas identified for oil and gas exploration. Findings of the Mozambican demersal surveys are described in survey and/or summary reports (IMR, 1977, 1978a, b, c; Sætre and Paula e Silva, 1979; Brinca *et al*., 1981, 1983, 1984; IMR, 1990a, b, c; Sætersdal *et al*., 1999; Johnsen *et al*., 2007; Olsen *et al*., 2009; Krakstad *et al*., 2015).

Reef-associated fishes (Lutjanidae, Serranidae) made a higher contribution to catch weight on the northern shelf (Figure 7.4, Appendix 7.6), whereas catches on the central shelf were dominated by small pelagics, including *Thryssa vitrirostris* (Engraulidae), *Pellona ditchela* (Pristigasteridae) and *Decapterus russelli* (Carangidae). Semi-demersal *Leiognathus elongatus* and typical demersal taxa such as *Upeneus* spp. (Mullidae), *Johnius* spp. (Sciaenidae) and several caridean and penaeid prawns were also plentiful in the central area. These taxa were still common 17 years later (after 2007), when surveys targeted crustaceans to support prawn stock assessments.

Small pelagic fishes (Leiognathidae and Clupeidae) were also common in the southern area, where large catches of Sparidae (mainly *Polysteganus coeruleopunctatus*) were also made. Fewer crustaceans were caught in the south, compared to the central Sofala Bank.

Trawl surveys by other vessels have often been undertaken on the Mozambique shelf (Fennessy and Everett, 2015), but reports are not readily available. Most shallow surveys focussed on the central Sofala Bank to assess prawn stocks. Surveys in the late 1970s and early 1980s reported mostly small pelagics, along with demersal Sciaenidae, Haemulidae, Synodontidae, Mullidae and Trichiuridae on the Sofala Bank (Cristo, 1983). Trawl catches by *Nansen* surveys were similar in the central and southern slope zones

(200–800 m depth), with abundant mid-water fish (Myctophidae) and demersal crustaceans, notably caridean prawn *Plesionika martia*. Elasmobranch catches declined over time (although this may be distorted by catches of a few large individuals), while the Chlorophthalmidae increased in prominence in the central zone (Figure 7.4). The commercially important pink prawn *Haliporoides triarthrus* was common in all slope catches, and other commercially important prawns *Aristaeomorpha foliacae*, *Penaeopsis balsii* and *Aristeus antennatus* also contributed.

Deeper surveys on the slope (200–800 m depth) by the Spanish research vessel RV *Vizconde de Eza* (2007–2009) found abundant *H. triarthrus* in central and southern Mozambique (IIP, unpublished data). The most important fish species were *Chlorophthalmus*, *Cubiceps* and *Synagrops*, with notable quantities of elasmobranchs and Macrouridae (rat-tails). Similarly, deep-water trawls by the FV *Caroline* for SWIOFP in 2012 caught commercial quantities of *H. triarthrus* and large numbers of *Cubiceps* and *Chlorophthalmus* (Everett *et al*., 2015a, b).

Madagascar and Comoros subregion

Slope trawls were rarely attempted on the first two surveys off Madagascar (1983, 2008) and even shelf trawls were seldom attempted on the second survey owing to large expanses of untrawlable seabed. Surveys of the east (2008) and west (2009) coasts of Madagascar were done in partnership with the regional ASCLME/SWIOFP Programmes (Appendix 7.2). The east coast shelf is narrow, with few trawlable areas, while some parts of the southern shelf are trawlable to 130 m depth. The west coast shelf is wider, but reef-like ridges towards the shelf break preclude bottom trawling in many places. Available maps of the seafloor were imprecise. Nevertheless, a total of 52 demersal trawls were completed (Figure 7.5, Appendix 7.2; Alvheim *et al*., 2009). Apart from one trawl, only oceanographic sampling was

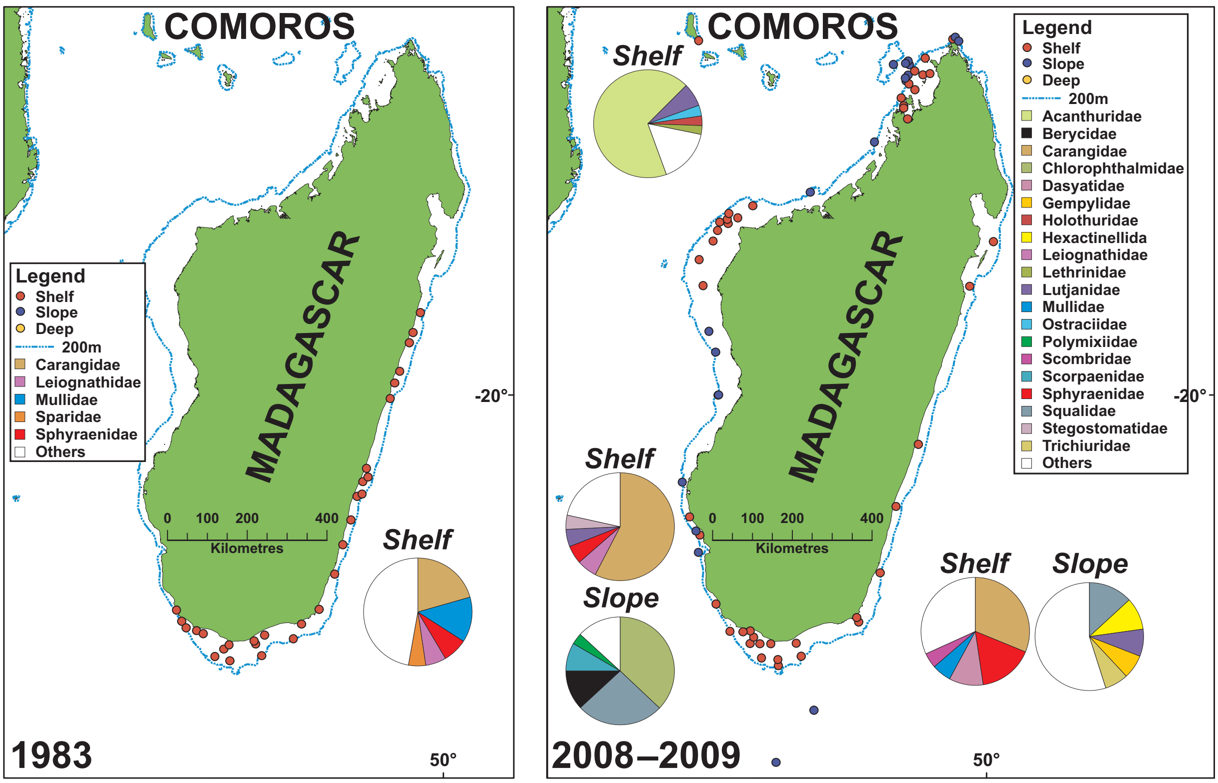

Figure 7.5 Bottom trawl sampling stations around Madagascar, and off Comoros, with catch composition (percentage by weight) by family.

undertaken around the Comoros islands, because the seafloor around them plunges steeply to abyssal depths (Roman *et al*., 2009; Appendix 7.2).

Catches along the southern and eastern Madagascar shelves were dominated by *Trachurus* and *Selar* (Carangidae) and *Gazza* and *Leiognathus* (Leiognathidae) (Figure 7.5, Appendix 7.7). Shelf catches on the west coast were also dominated by Carangidae, particularly *Trachurus* and *Decapterus*. Members of the Carangidae in the southern region are likely associated with higher primary productivity / upwelling which occurs there (see Chapter 4). Mullidae and Leiognathidae made lesser contributions. Species composition of shelf catches along the east and west coast zones were broadly similar, but more detailed analyses are required. Few other shelf surveys are available for comparison, and these mostly focussed on shallow areas (<50 m depth) where commercial prawn fisheries operate along the west coast. The *Nansen* did not survey waters <20 m depth, especially after 1994. Fennessy and Everett (2015) reviewed available survey reports and apart from Penaeidae prawns, noted mainly Sciaenidae, Leiognathidae, Haemulidae, Trichiuridae, Theraponidae and Nemipteridae as being commonly caught.

Only three trawls were possible on the upper slope of the south and east coast during the 2008 survey; *Chlorophthalmus* was overwhelmingly dominant. Unidentified Myctophidae and shrimps predominated on the slope off the west coast, and sharks of the Squalidae family contributed by weight off both coasts (Appendix 7.7). Everett *et al*. (2015b) reported on an upper slope survey off southwestern Madagascar, at depths from 300 to 600 m; here, *Neoscopelus microchir* dominated catches, with lower numbers of Chlorophthalmus and prawns *Aristaeomorpha foliacea*, *Aristeus antennatus* and *H. triarthrus*. These taxa together contributed almost 50 percent by number to overall catches from the region. Interestingly, Everett *et al.* (2015b) showed a clear difference in the community structure of upper slope fauna across the Mozambique Channel, with ecologically different soft sediment demersal communities in southwest Madagascar compared to southern Mozambique.

Mascarene subregion (Seychelles, Mascarene Plateau, Mauritius)

Few trawls were undertaken around Seychelles (1978) and on St. Brandon and Nazareth Banks north of Mauritius (2008 and 2010; Figure 7.6), mainly because of uneven bottom topography and/or corals. As an alternative to bottom trawling, some surveys have focussed on the feasibility of demersal fish traps, and acoustic assessment of deeper (100–350 m) demersal fishes. Surveys are reported on by IMR (1978c), Strømme *et al*. (2009, 2010), and Krakstad *et al*. (2010).

Lutjanidae (snappers) were common in shelf trawl catches, but had declined by 2007 (Appendix 7.8). The Mullidae (*Upeneus* spp.) and Synodontidae (*Saurida undosquamis*) were reasonably consistently present in both periods. The small pelagic fish *Engraulis japonicus* (Engraulidae) was prominent in the first period on the shelf and appears to have been replaced by Leiognathidae (*L. leuciscus*), Carangidae (*Decapterus* spp.) and cephalopods in the second period.

Results are based on few trawls, and need to be interpreted with caution. The unsuitable bottom topography made trawling very difficult in the Mascarene subregion, particularly on the slope, and catch volumes were variable, with high diversity.

7.4 Regional patterns in catch densities

Despite the unbalanced distribution of trawl surveys over time and space, broad patterns in fish distribution and densities are apparent. Densities were relatively higher in the Somali Coast subregion than elsewhere, and also higher on the shelf than on the slope (Figure 7.7). The densities in the Somali Coast subregion may have been artificially inflated as a result of the non-random selection of trawl locations in this subregion prior to 1980 (see Appendix 7.1). Densities were highly variable (0.1–2.4 t/nm^2) over the two survey time periods (1975–1990 and 2007–2014), between the five subregions, and between the shelf and upper slope

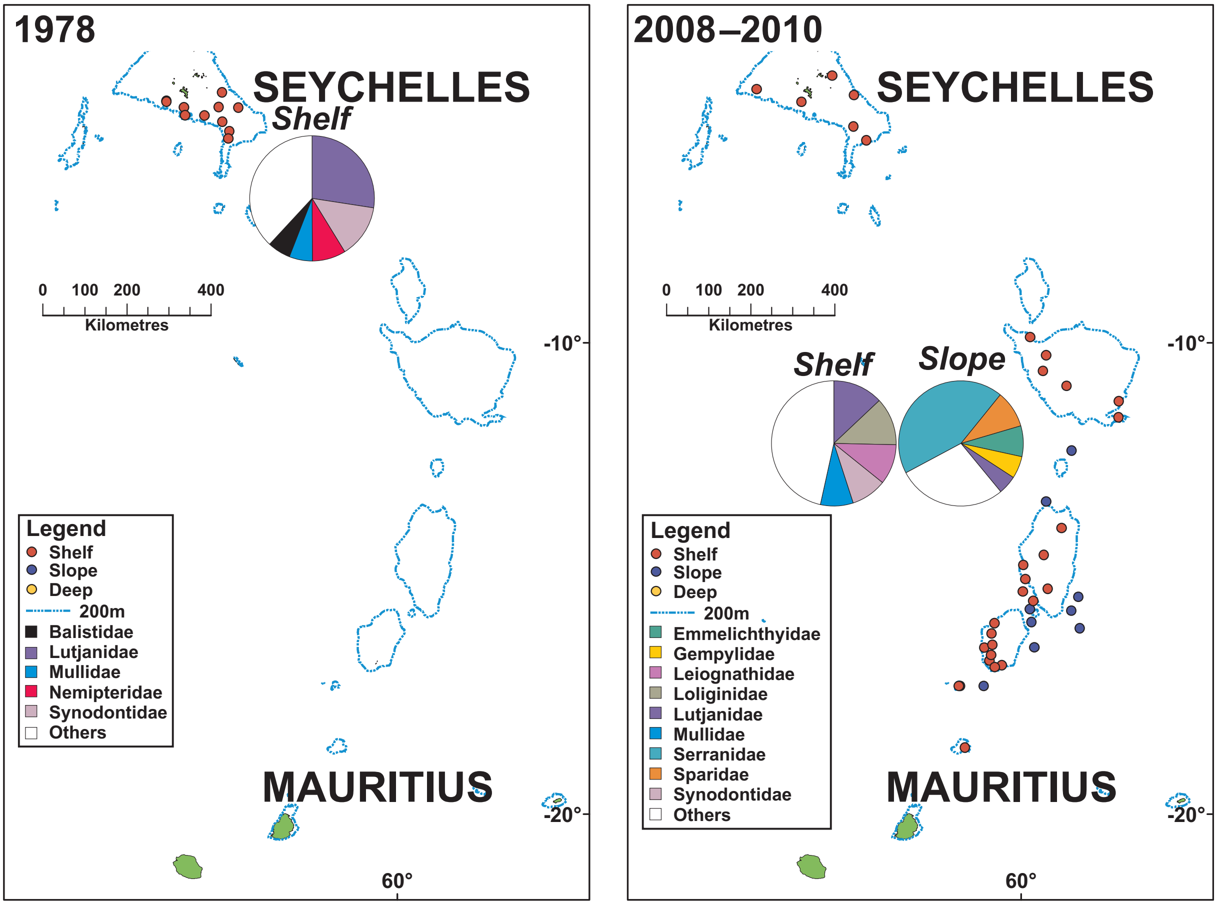

Figure 7.6 Bottom trawl sampling stations and catch composition (percentage by weight) by family in the Mascarene subregion.

depth zones. Relative contributions (overall and by taxon) of commercially important and potentially important demersal taxa to overall densities were generally low (Figure 7.7).

Densities of Lutjanidae were consistent across shelf subregions, particularly in 2007–2014 surveys (Figure 7.7 – top). Sparidae exhibited a bipolar or subequatorial distribution, occurring in Somalia in the north and in southern Mozambique/southern Madagascar, but not in-between. Crustaceans predominated on the Mozambique shelf, consistent with the information from prawn trawl fisheries. No shallow-water surveys were done in western Madagascar – hence the abundant prawn stocks along that coast (from fisheries information) were not replicated by surveys. Crustaceans featured prominently in trawls on the slope across the Western Indian Ocean, but much less so in the east of the region (Figure 7.7 – bottom).

Density estimates based on aggregated data are broad, and more detailed analysis is required to render finer-scale patterns. Detection of within-subregion patterns and seasonality, either in relative composition or overall density, will require examination of subsets of the data. For example, the discrepancy between demersal fish densities off northern and southern Somalia, and the strong influence of the SW monsoon conditions on distribution patterns (Strømme, 1984) are not apparent from findings presented here.

Estimates produced from *Nansen* surveys are not dissimilar to those produced by other surveys in

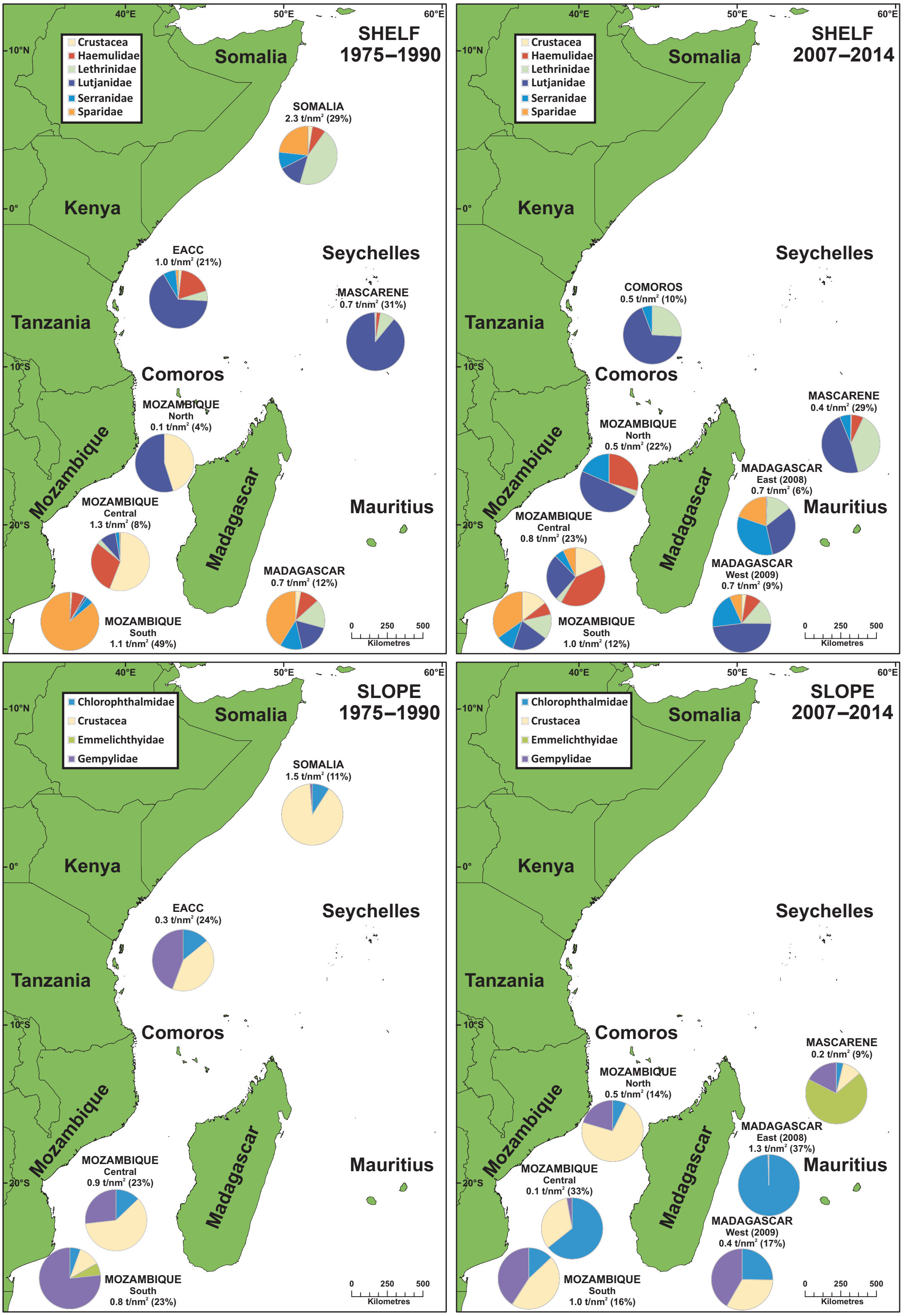

Figure 7.7 Densities (t/nm²) and percentage relative contributions of commercially important/ potentially important demersal taxa, based on bottom trawl surveys in two time periods, on the shelf (top; 20–200 m depth) and slope (bottom; 200–800 m depth).

the Western Indian Ocean (Table 7.2). Sanders *et al*. (1988) calculated an average of 0.29 t/nm^2 (mainly for depths <200 m) in the Western Indian Ocean, based on numerous surveys, including those listed below and from the *Nansen*. Sætersdal *et al*. (1999) and Gulland (1970) suggested 0.7 t/nm^2 and Neyman *et al*. (1973) suggested a level of 0.88–1.46 t/nm^2.

Interestingly, the overall density estimate based on approximately 1 500 *Nansen* trawls over both periods and all five subregions is 1.26 t/nm^2 ± SD 2.08, but this figure is skewed by the high numbers of trawls on the relatively productive Mozambique shelf. It also includes a high proportion of small pelagic and semi-demersal fishes caught by the bottom trawls. Thus this estimate of demersal productivity is partially inflated by pelagic productivity.

Nevertheless, it is unlikely that the Western Indian Ocean would attain fish density levels similar to the highly productive upwelling regions of the world. Comparative estimates of regional demersal fish densities (Gulland, 1970; Sætersdal *et al*., 1999) rank the Southeast Atlantic highest (15.8 t/nm^2, Benguela Current upwelling region), followed by the Arabian Sea and adjacent gulfs (13.4 t/nm^2), Eastern Central Pacific (10.3 t/nm^2, Humboldt Current and Peruvian upwelling) and the Southwest Indian Ocean (8.2 t/nm^2).

From a Western Indian Ocean regional perspective, densities of commercially important crustaceans are concentrated on the shelf of central Mozambique and off southwest Madagascar. Haemulidae occur along the African mainland, while Lethrinidae and Lutjanidae are patchily aggregated, off Somalia and Kenya/Tanzania respectively. Serranidae are widespread, mostly at low densities, while Sparidae are concentrated sub-equatorially, off Somalia and the southern part of the region. On the slope, crustaceans are most abundant off Mozambique and western Madagascar. Chlorophthalmidae and Gempylidae are concentrated in the south, while Emmelichthyidae are at low densities off southern Madagascar and in the east of the region.

Notwithstanding the potential for upwelling-generated nutrients and increased productivity in the Western Indian Ocean (see Chapters 4 and

Table 7.2 Densities (t/nm^2) of demersal resources from various sources other than on the RV *Dr Fridtjof Nansen* in the Western Indian Ocean. (*excluding *Decapterus* spp).

Region	Source/Vessel	Date	Density	Source
Kenya – Ungwana Bay <200 m	Various	Prior to 1978	0.4–1.1	Gulland, 1978
Kenya – Ungwana Bay >200 m	Various	Prior to 1978	0.2–0.3	Gulland, 1978
Tanzania – central region <200 m	Various	Prior to 1978	0.5–0.6	Gulland, 1978
Tanzania – central region >200 m	*Professor Mesyatsev*	1975–1977	0.8	Birkett, 1979
Tanzania (<60 m)	*MV Mafunzo*	2006, 2007	0.3–0.4	Mahika et al., 2008
Mozambique – Sofala <200 m	*Professor Mesyatsev*	1975–1977	0.4	Birkett, 1979
Mozambique – Delagoa <200 m	*Professor Mesyatsev*	1975–1977	0.5	Birkett, 1979
Mozambique – Delagoa >200 m	*Professor Mesyatsev*	1975–1977	0.4	Birkett, 1979
Seychelles <200 m	Various	1968, 1976–1977, 1979	0.3–1.0*	Tarbit, 1980
Madagascar – west coast <200 m	Unspecified	Prior to 1978	0.5	Gulland, 1978
Madagascar – west coast >200 m	Unspecified	Prior to 1978	0.3	Gulland, 1978
Madagascar – east coast <200 m	Unspecified	Prior to 1978	0.4	Gulland, 1978
Madagascar – east coast >200 m	Unspecified	Prior to 1978	0.2	Gulland, 1978

5), the *Nansen* surveys demonstrated that, apart from crustaceans, there are limited resources on the generally narrow shelf and upper continental slope to support demersal trawl fisheries. This is supported by the relatively low coastal fisheries' catches from the region, which were remarked on by Bakun *et al.* (1998) and more recently by van der Elst *et al*. (2009). The major demersal trawl fisheries are concentrated in regions where there is considerable riverine influence – likely localized sources of nutrients for shelf and continental slope demersal habitats – as recently demonstrated for the east coast of South Africa (reviewed in Fennessy *et al*., 2016). Thus nutrients from terrestrial sources appear to be of greater importance than upwelled sources for demersal organisms over soft sediments in parts of the Western Indian Ocean, particularly south of the equator.

7.5 Sampling the seafloor using other methods

Apart from trawls, acoustic recordings, baited traps and hook-and-line methods have occasionally been used to sample demersal species in rocky areas that could not be trawled.

Acoustic assessments use echo-sounders, but cannot distinguish fish close to the seabottom from the bottom itself, and the method is therefore not precise. Acoustic recordings can, however, still provide information on distribution and relative density of a stock, particularly at night, when fish rise from the bottom to feed. The distribution of demersal fish on the Seychelles Bank at <50 m depth is shown in Figure 7.8, based on acoustic recordings made during the 2008 *Nansen* survey. The map shows backscattering s_A values allocated to demersal species sampled with 1 nautical mile resolution, and indicates areas of different fish densities. High spatial variability in fish density is observed, with the highest relative densities associated with the bank's edges (especially the eastern edge), because productivity is higher along the edges than over the central bank. This can further be explained by the westward directed main surface current, with upwelling and increased productivity occurring where it first hits the bank edge. Species diversity is high on the Mascarene Plateau, and a typical bottom trawl catch may comprise of >30 different species, of different shapes, colours and sizes (Figure 7.8).

Acoustic recordings of demersal fish are also possible on steep slopes, although the bottom shadow effect is even greater in these areas. Because bottom trawling is often not possible on steep rough grounds, baited traps or hook-and-line methods

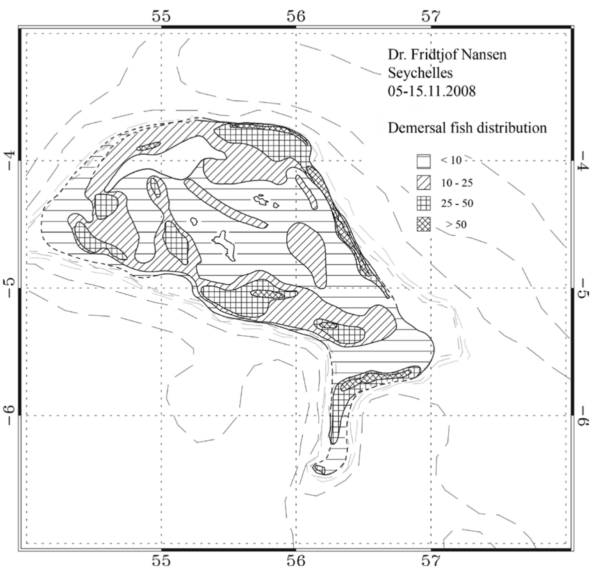


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Figure 7.8 Distribution of demersal fish on the Seychelles Bank based on acoustic recordings (top) and typical reef species found on the banks between Mauritius and Seychelles including *Lethrinus rubrioperculatus, Variola louti, Naso tuberosus, Acanthurus dussumieri, Scarus* sp., *Pomacanthus imperator, Zebrasoma* sp., *P. semicirculatus, Epinephelus flavocaeruleus.*

are required to verify species composition, as done during a survey at St Brandon and Nazareth Banks, north of Mauritius, in 2010. Generally, acoustic observations of fish on the slope were good, especially along the eastern edge, which faces the main current direction, and is not as steep as the western edge. Typically, densities increased over a relatively narrow depth range of 200 to 400 m. Here, recordings of reef-like structures also suggested the presence of deep water corals, which may enrich the area.

Trapping and hook-and-line methods can assist in identifying species that occur in rocky areas, which are generally under-sampled by trawls. However they are not a good method for biomass estimation, because the area of attraction is difficult to estimate, and catches can be influenced by factors such as bait-type, soak-time, and competition between species, sex or size-classes. Several trap types were tested on *Nansen* surveys in 1978–1983 and in 2010 (Figure 7.9). Baited traps were set singly or in strings of up to 10 traps at a time, mostly on the shelf <200 m deep (88 percent of 467 traps). Most trapping took place in Mozambique (53 percent), Kenya and Tanzania (33 percent) and on the Mascarene Plateau (14 percent). Traps were generally set overnight, with soak-times of 8 to 20 hours. Fish made up 80 percent (by numbers) of trap catches, followed by crustaceans (14 percent), sharks and rays (6 percent) and molluscs (<1 percent). Catches included toxic species, such as the scorpion-, wasp- and puffer fishes, and also species too small or unattractive to have a market value – these included cardinal- and filefishes, and several small crab species. Families with potentially high commercial value are shown in Figure 7.10.

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Figure 7.9 A large steel frame fish trap prototype tested on Nazareth Banks, Mauritius in 2010 (184 x 153 x 80 cm; 50 kg) (Krakstad *et al*., 2010).

On the Mascarene Plateau, emperors (Lethrinidae) were common near Mauritius in 2010, but snappers (Lutjanidae) dominated near Seychelles in 1978. Snappers were also most abundant in Kenya and Tanzania, followed by emperors and groupers (Serranidae). Further south, in Mozambique, seabreams (Sparidae) made up the largest proportion of catches, but they were virtually absent in samples from elsewhere. Related to this, an experimental trap fishery in Mozambique in the late 1990s caught mostly seabream *Polysteganus coeruleopunctatus* (Abdula and Lichucha, 2003). Spiny lobsters (Palinuridae) were caught in small numbers in Mozambique, Kenya and Tanzania – possibly because of an unsuitable trap design.

Hook-and-line (handlines and bottom-set longlines) were used in the 1970s and 1980s in Mozambique, Kenya, Tanzania and Seychelles (Figure 7.10). Longline hook numbers varied from 200 to 500 per set. Overall catch composition was dominated by sharks, with a consistent presence of snappers, particularly in Mozambique. Of interest, the semi-industrial handline fishery in Mozambique catches a high proportion of seabreams in the south and snappers in the central region (Fennessy *et al*., 2012).

Baited traps and hook-and-line sampling methods were infrequently used by the *Nansen* in Western Indian Ocean surveys, because they do not fit well into multi-disciplinary survey strategies.

BOX 7.2

Sampling the sediments and benthic fauna of the seafloor

Marine macrobenthos are small invertebrates (retained by 500–1 000 µm sieve meshes) occurring either within or on seafloor sediments (Gray, 2002). Macrobenthos have functional roles essential to many ecosystem processes, such as altering chemical conditions at the sediment-water interface, promoting decomposition, sequestering contaminants, and recycling nutrients (Hewitt *et al*., 2008; Gray and Elliott, 2009). They have limited mobility and are influenced by the surrounding environment, making them suitable for pollution monitoring (Pearson, 2001) and studies of community dynamics relative to a changing environment (Zajac, 2008).

Nansen surveys in Mozambique (2007) and western Madagascar (2009) used a Van Veen grab (0.1 m^2) to collect sediments and benthos for studies on benthic biodiversity, habitat distribution and pollution, including presence of metal and oil hydrocarbons (Johnsen *et al*., 2007). Two sieve mesh sizes were used, the first to retain larger debris and fauna (>5 mm) and the second to retain macrobenthos >1 mm. Samples from Mozambique have not yet been fully analysed. The Madagascar samples were collected along six transects, at depth intervals of 20 m, 40 m, 60 m, 100 m, 150 m and 200 m. Coarse-grained coralline sands, with or without bioclastic material, characterised sediments at Transects 3, 5 and 6 (see below). Fine-grained sediments with a high proportion of biogenic material were evident at Transects 3 and 4. Muddy habitats were most prolific near the coast, and along Transect 4 in particular, there was a large depositional area of mud. Biological analysis of samples showed them to be devoid of any soft-bodied metazoan fauna, however, there was an extraordinary number of planktonic and benthic extant and fossil protist Foraminifera.

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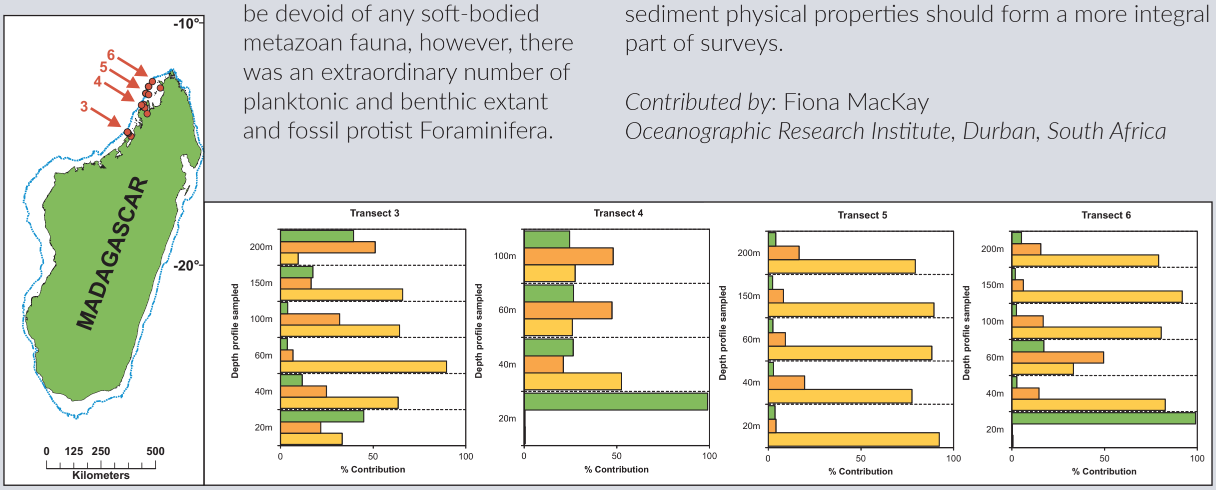
Van Veen grabbed seabed sediments being sampled for distributional analyses.

Future efforts to collect macrofauna and associated sediment physical properties should form a more integral part of surveys.

Contributed by: Fiona MacKay
Oceanographic Research Institute, Durban, South Africa



Sand and mud distribution along Transects 3–6, on the Madagascar shelf.

For example, to undertake trapping, the *Nansen* would either have to remain near the setting stations, or interrupt subsequent sampling activities to return and retrieve the gear – both alternatives are time-consuming and costly. A better option is to survey rocky areas in the Western Indian Ocean using commercial trap fishing vessels. This method led to the discovery of spiny lobster stocks along the east coast of South Africa (see Groeneveld *et al*., 2012) and in Mozambique (de Sousa, 2001).

From 2007 onwards, high to very high-resolution seabed mapping was undertaken, using a multi-beam echo sounder – these data have not often been reported upon. Also from 2007 onwards, benthic grabs have been used to collect macrofauna and associated sediments from the seafloor, for spatio-temporal studies ranging from pollution monitoring (Pearson, 2001) to community dynamics. We used specialists in these latter fields to describe the methods (Boxes 7.2 and 7.3).

7.6 Conclusions

Bottom trawling and seabed mapping with an echo sounder are routine sampling activities on *Nansen* surveys. These data are available for most shelf-areas of the Western Indian Ocean, albeit collected irregularly over space and time. Nevertheless, our study is the first to synthesize demersal trawl data collected by the *Nansen* over the past four decades, to investigate region-wide species distribution and density patterns, relative to ecosystem processes and physical features. The findings should be seen as preliminary.

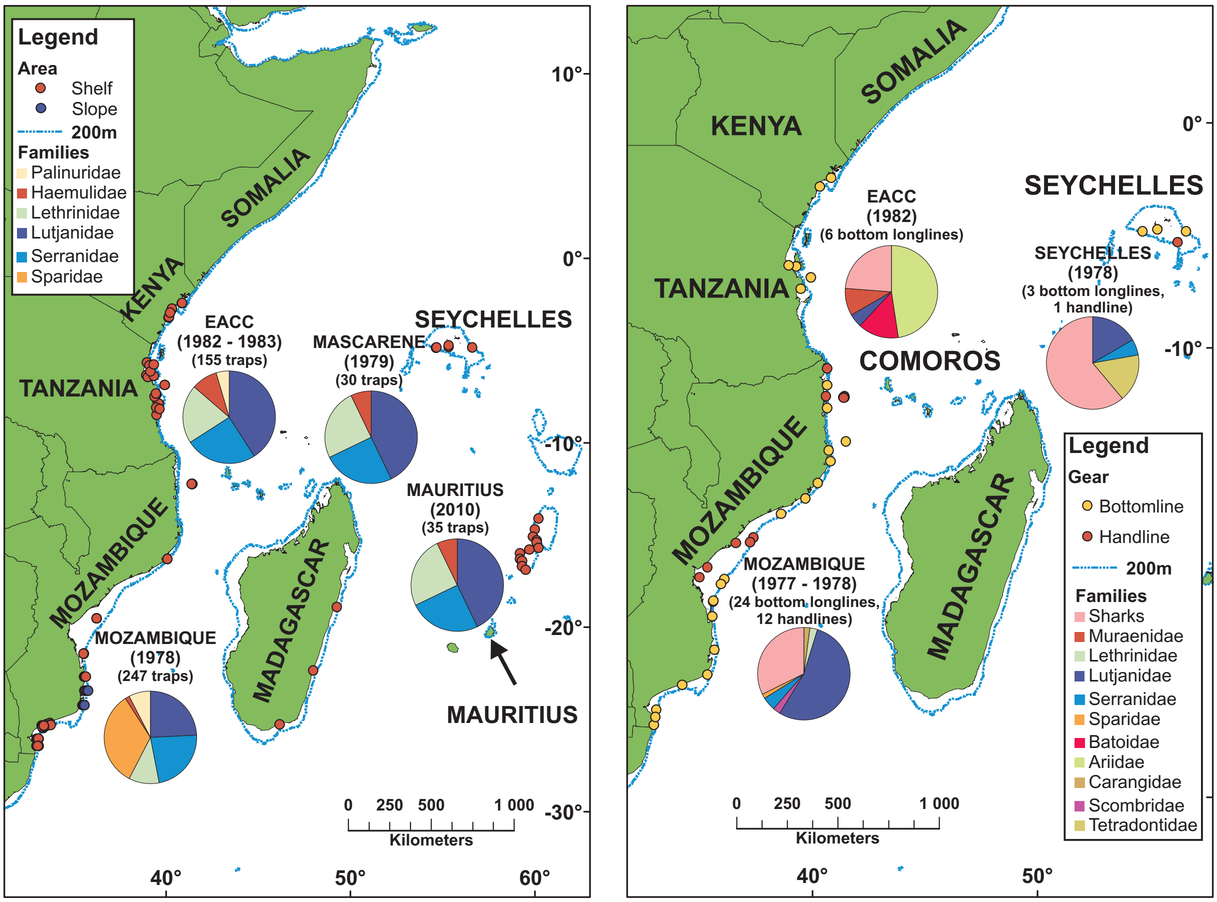


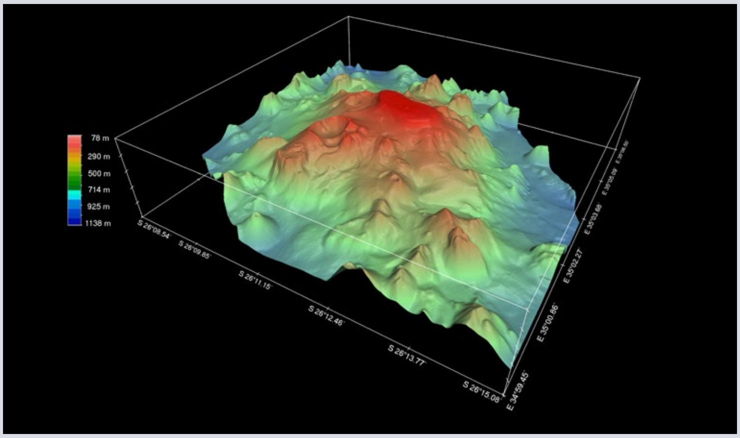
Figure 7.10 Gear deployments by the RV *Dr Fridtjof Nansen* and relative contributions of commercially important fish families in catches (pie charts, percentage by number) from trap surveys (left) and hook-and-line surveys (right).

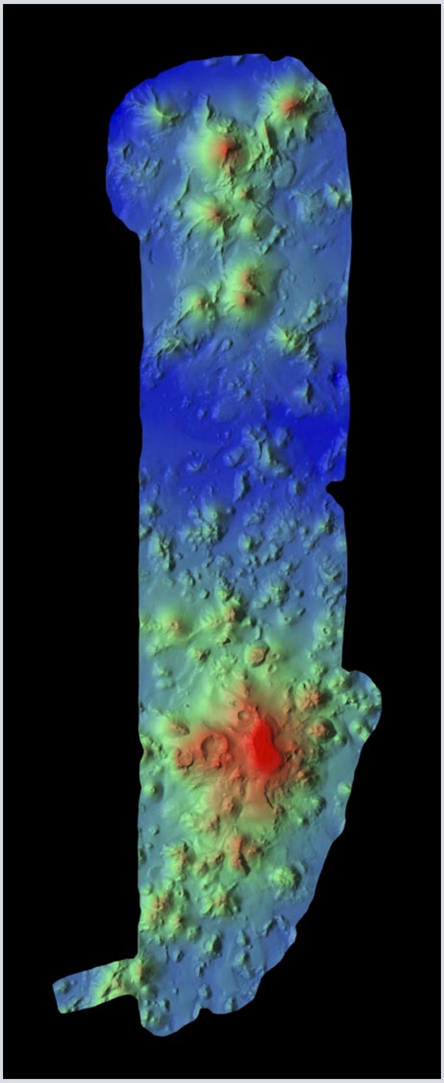
BOX 7.3

Mapping the seabed

From 2007 onwards, high to very high-resolution seabed mapping was undertaken on *Nansen* surveys, using the EM 710 multibeam echo sounder with operating frequencies of 70 to 100 kHz. In practice, the maximum data acquisition depth is limited to 1 500 m, covering a seabed area of up to 5.5 times the water depth, in good sea conditions. The system is mostly used to check that bottom conditions are suitable for trawling operations – in other words, to avoid trawling in areas covered by coral beds or sponges, which would destroy them or damage the trawl equipment. To generate accurate maps of the seabed, the *Nansen* steams along systematic transects, so that each new transect overlaps with the previous one. Survey speed is reduced to obtain sufficient coverage at greater depths.

By way of example, the *Nansen* mapped the Almirante Leite Bank, approximately 110 nautical miles east of Maputo along the Mozambique coast, in 2007. Several seamounts were identified, rising to a shallowest depth of 80 m from the sea surface (areas coloured red), and surrounded by bottom depths of more than 1 100 m (coloured dark blue). The images show that the seamounts are of volcanic origin, with several craters being visible.





Seafloor maps of the Almirante Leite Bank mapped with the EM710 echo sounder. Left: 3-dimensional detail; Right: the Bank and adjacent area.

Nansen surveys demonstrated that, apart from crustaceans, there are limited resources on the generally narrow shelf and upper continental slope of the Western Indian Ocean to support demersal trawl fisheries. This is supported by relatively low coastal fisheries catches from the region, compared to those from West Africa, for example. In spite of low abundance, demersal taxa have high diversity, even in the absence of many reef-associated species, which were presumably under-sampled by bottom trawling.

Broad geographical patterns in fish distribution and densities could be identified. Densities were relatively higher in the Somali Coast subregion than elsewhere, and also higher on the shelf than on the slope. Densities of snappers (Lutjanidae) were consistent across shelf subregions, whereas seabreams (Sparidae) occurred in Somalia in the north and in southern Mozambique/southern Madagascar in the south, but not in tropical waters in-between. Crustaceans predominated on the Mozambique shelf.

The major demersal trawl fisheries are concentrated near areas of riverine influence. River outflows are likely sources of nutrients for localized shelf and continental slope demersal habitats. Thus nutrients from terrestrial sources appear to be of greater importance than upwelled sources for demersal organisms over soft sediments in the southern part of the Western Indian Ocean.

Pelagic fish were frequently caught in bottom trawls, together with demersal species, presumably because they school low down in the water column at certain times. Seasonal differences in species composition of bottom trawl catches, particularly in Somalia, may reflect fish behaviour when confronted with intrusions of low oxygen water along the seafloor.

The unsuitable bottom topography made trawling very difficult in the Mascarene subregion, particularly on the slope. Large parts of the Madagascar shelf and slope were also untrawlable, because of reef structures. The dynamic multidisciplinary sampling strategy used by the *Nansen* precludes static sampling methods, such as trapping or hook-and-line fishing, and hence these rocky substrates remain under-sampled, compared to trawlable areas.

Other demersal areas that have been under-sampled by the *Nansen* are waters shallower than 20 m depth and deeper than 200 m, and, because of the security situation, the shelf and slope north of 10 °S after 2007 (including Tanzania, Kenya, Somalia and Seychelles). The recent focus on wider ecosystem aspects of demersal habitats using non-trawl methods holds promise, even though sampling protocols are still being developed. The adherence to a consistent approach to bottom trawling on *Nansen* surveys has added considerable value to the data, and will facilitate future in-depth analyses. ■

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