Pelagic resources based on acoustic recordings and trawl sampling

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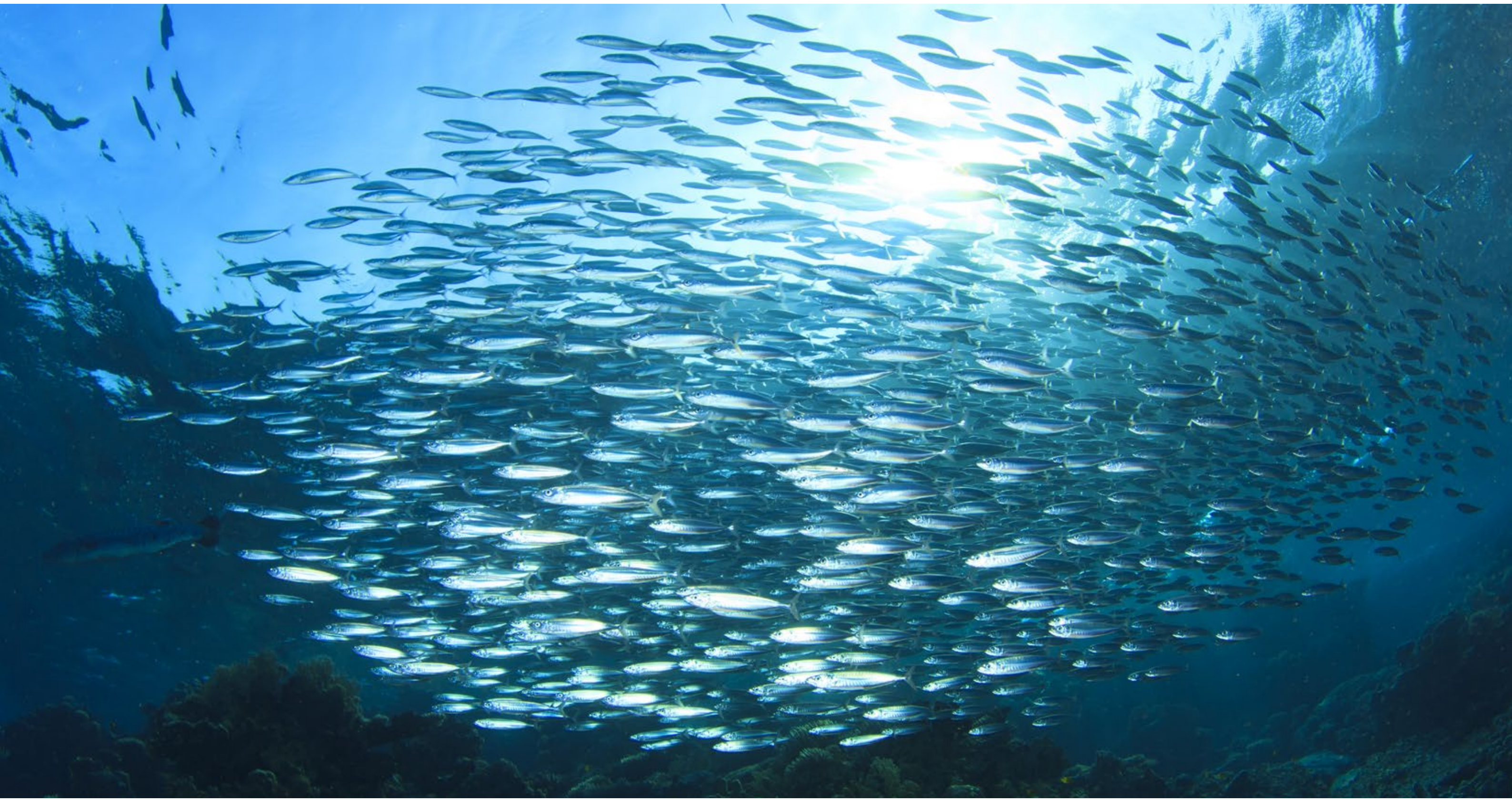
Chapter 6



Pelagic resources based on acoustic recordings and trawl sampling

Jens-Otto Krakstad, Cosmas Nzaka Munga and Tore Strømme

“The initial *Nansen* surveys in 1975 provided the first estimates of pelagic fish biomass and distribution in the region.”

Abstract

Pelagic fishes live in the upper layers of the water column, below the sea surface but well-above the seafloor. Many pelagic fish species form vast schools in areas of high primary productivity. They range in size from small coastal forage fish species, such as anchovies and sardines, to large oceanic predators, such as tunas and swordfish. The RV *Dr Fridtjof Nansen* used a combination of acoustic methods (echo-integration) and trawl sampling to quantify the "small pelagic fish" resources of the Western Indian Ocean. Large pelagic fish species were not sampled. The initial *Nansen* surveys in 1975 provided the first estimates of pelagic fish biomass and distribution in the region, and these early estimates remain the only reference points for some countries. Common families were clupeids (sardines), engraulids (anchovies), carangids (jacks, scads), scombrids (mackerels), sphyraenids (barracudas), trichiurids (hairtails) and myctophids (mesopelagic fishes). Carangids and clupeids were distributed in shallow shelf areas, from the Horn of Africa, along the coast to the Mozambique Channel, and around Madagascar, Mauritius, the Mascarene Plateau, and the Seychelles. Engraulids were more abundant in the southern part of the East Africa Coastal Current subregion, the Mozambique Channel and around Madagascar, associated with areas of high primary production. Myctophids were widely distributed off the shelf throughout the Western Indian Ocean, with high densities off the Horn of Africa. *Nansen* surveys in Kenya and Tanzania during the early 1980s found low biomass of pelagic resources, and this information averted overcapitalization on a new fishing fleet. Surveys, done 25 years apart, found similar abundance, distribution patterns and species composition of pelagic fishes along the southeast coast of Madagascar. In Mozambique, clupeid biomass was markedly lower in surveys done in 2007 and 2014, than in pre-1990 surveys. This finding was supported by declining catches experienced in the artisanal fishery. Pelagic fish often migrate widely, and stocks that cross international boundaries are therefore regional, instead of belonging to a specific country. Detailed studies are required to determine seasonal migrations, and to develop a more regional management approach, based on information from acoustic surveys over a large geographical area. The *Nansen* is well-suited to undertaking regional surveys of this kind.

Previous page: Sardine shoals in inshore waters. © Shutterstock.com/Rich Carey

6.1 Introduction

Pelagic fish live in the layer of water between the sea surface and the seafloor, unlike demersal fish (see Chapter 7), which live on or near the seafloor. Pelagic fish range in size from small coastal forage fish, such as herrings and sardines, to large oceanic predators, such as tunas, swordfish and oceanic sharks. They are usually agile swimmers with streamlined bodies, and many species form dense schools. Depending on the ocean layer that they inhabit, pelagic fish can be subdivided into species occurring in the sunlight zone between the surface and 200 m depth (epipelagic), those living in the twilight zone between 200 and 1 000 m depth (mesopelagic; Box 6.1), and those living in the midnight zone between 1 000 and 4 000 m depth (bathypelagic). Few known species live deeper than 4 000 m (abyssopelagic), in complete darkness, cold temperatures and under high pressure.

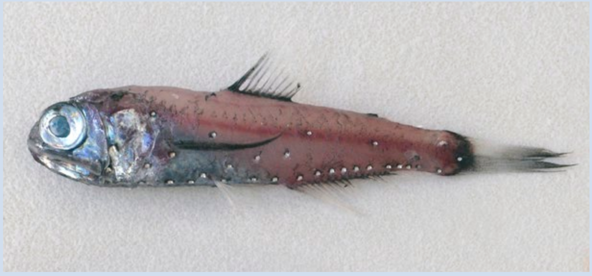
Early surveys of pelagic fish resources in the Western Indian Ocean showed relatively low stock

BOX 6.1 Mesopelagic fish - living in the twilight zone

Mesopelagic fish (mostly lanternfish belonging to the Myctophidae family) are small fish of many different species living in the ocean's twilight zone, at depths between 200 and 1 000 m. They form one of the most characteristic features on echo-sounder displays of ships sailing the world's oceans, namely the deep scattering layer. This layer has been known for as long as echo-sounders have been used on ocean-going ships. However, only since the late 1970s have mesopelagic fish attracted attention as a potentially harvestable fisheries resource (Gjøsæter and Kawaguchi, 1980).

The global estimate of mesopelagic fish biomass amounts to more than 100 million tonnes (Lam and Pauly, 2005; Irigoien *et al*., 2014), making it the world's most abundant vertebrate group. Gjøsæter and Kawaguchi (1980) pointed out that most of the gears used in surveys obviously underestimate mesopelagic fish biomass, and Kaartvedt *et al*. (2012) concluded, from an acoustic study in a Norwegian fjord, that a potential upgrading of the current global estimate of mesopelagic fish to 10^{10} tonnes — which is 100 times greater than the world's yearly fishery catch — would force us to rethink their role as predators on zooplankton, as prey for top predators, and as daily vertical transporters of organic matter from the surface to the deeper ocean.

The exploratory surveys of the RV *Dr Fridtjof Nansen* in the northwest Indian Ocean in 1975 and 1976 found that small pelagic fishes, such as sardines, anchovies and mackerels, were less abundant than expected, whereas mesopelagic fish were far more abundant than any other fish group (Sætersdal *et al*., 1999). This confirmed previous observations of abundant mesopelagic fish



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Benthosema fibulatum is one of several lanternfish species found in the Indian ocean.

eggs and larvae in the area (Nellen, 1973). Follow-up surveys of mesopelagic resources in the Sea of Oman and the Arabian Sea were carried out by the *Nansen* in 1975 to 1981 and in 1983 to 1984 (Gjøsæter, 1984). Systematic surveys in both Omani and Iranian waters led to an estimate of 8 to 20 million tonnes of mesopelagic fish (Gjøsæter, 1984).

Fishing trials by the *Nansen* in the Sea of Oman in 1983, using commercial trawls with mouth openings of 500 and 800 m^2 (Gjøsæter, 1984) reported a mean catch rate of 4.7 t/h, and the two best hauls recorded 18 and 100 t/h, respectively. Further trial fishing between 1993 and 1998 (Valinassab *et al*., 2007) concluded that the average catch of about 25 t/day was too low to cover fishing costs, and that more trials were needed to identify the best fishing method.

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biomass, at least an order of magnitude lower than along the Atlantic coast of Africa, where two highly productive eastern boundary upwelling areas support millions of tonnes of pelagic fish (FAO, 2016). Nevertheless, pelagic fish make up the bulk of reported landings from the Western Indian Ocean, with contributions from industrial fisheries for tunas and tuna-like species, reported to the Indian Ocean Tuna Commission (IOTC), and from artisanal fisheries, which land mainly small pelagic species for local consumption.

Pelagic surveys using hydro-acoustics were undertaken from the onset of the Nansen Programme in 1975, when the *Nansen* surveyed Somali waters. Hydro-acoustics based on echo-integration was a new and promising technology in the mid-1970s, with major technological advances taking place since then. Nevertheless, in design, acoustic surveys are still carried out in a similar manner as in the past. The quality of these early estimates (1970s and 1980s) was not of the same standard as in the later years. Evaluations of historic data have produced reliable (although less precise) time series information, comparable to more recent data. At present, acoustics are used as the method of choice in surveys of pelagic fish stocks around the world.

Apart from acoustics, trawl surveys (pelagic and demersal) were also used to estimate fish abundance. Ecosystem surveys in the Western Indian Ocean relied on simultaneous acoustic and trawl sampling, the latter relying on catches in a known "swept area". Pelagic trawls are mainly targeted at dense pelagic fish schools, to investigate the catch composition. Demersal (or bottom) trawls also catch some pelagic fish, near the seafloor or in the water column while descending or ascending from the sea surface. Trawl data from targeted trawls cannot be used for direct abundance estimation; such estimates rely on random trawling according to a statistical sampling design (see Chapter 7). This chapter deals with biomass estimates obtained from acoustic methods as well as catch rates reported from the swept area method for pelagic fishes.

6.2 Methods

The acoustics method can be used to estimate the density of pelagic fish, by transmitting sound waves of a certain frequency (commonly 38 kHz) into the water column, and then measuring the reflected (backscattered) sound energy. Data are collected by a research vessel carrying out a systematic survey grid covering the expected full distribution area of the fish stock. Through a process of interpretation and conversion, this reflected energy (measured as Area Backscattering Strength - s_A on the decibel scale) is translated into density of a certain fish species or fish target group per area. The conversion formula used includes the so-called target strength (TS) equation, which describes how much energy a specific fish species and body size reflects. The mean fish density per area is further multiplied with the size of the area surveyed, to calculate abundance. Several books (such as MacLennan and Simmonds, 1992) describe the techniques in detail. Recent surveys with the second *Nansen* in the Western Indian Ocean relied on two species categories when separating acoustic s_A values between groups of pelagic fish, as these two groups show different acoustic properties. PEL1 comprised of fish species belonging to the families Clupeidae (sardines) and Engraulidae (anchovies), whereas PEL2 comprised of members of the Carangidae (scads, jacks) Scombridae (mackerels), Sphyraenidae (barracudas) and Trichiuridae (hairtails) families (Figure 6.1). Biomass estimates are therefore reported for these fish groups.

During acoustic surveys, targeted trawling is carried out to identify species composition in the survey path, to determine the proportion by species, and to obtain representative samples of fish size distribution. Both pelagic and demersal trawls are used for sampling, depending on the position of the fish in the water column, as well as the trawled depth.

Some of the *Nansen* surveys in the Western Indian Ocean combined a swept area survey with an acoustic survey (for example, in Kenya and Tanzania in 1982–1983 and several surveys in

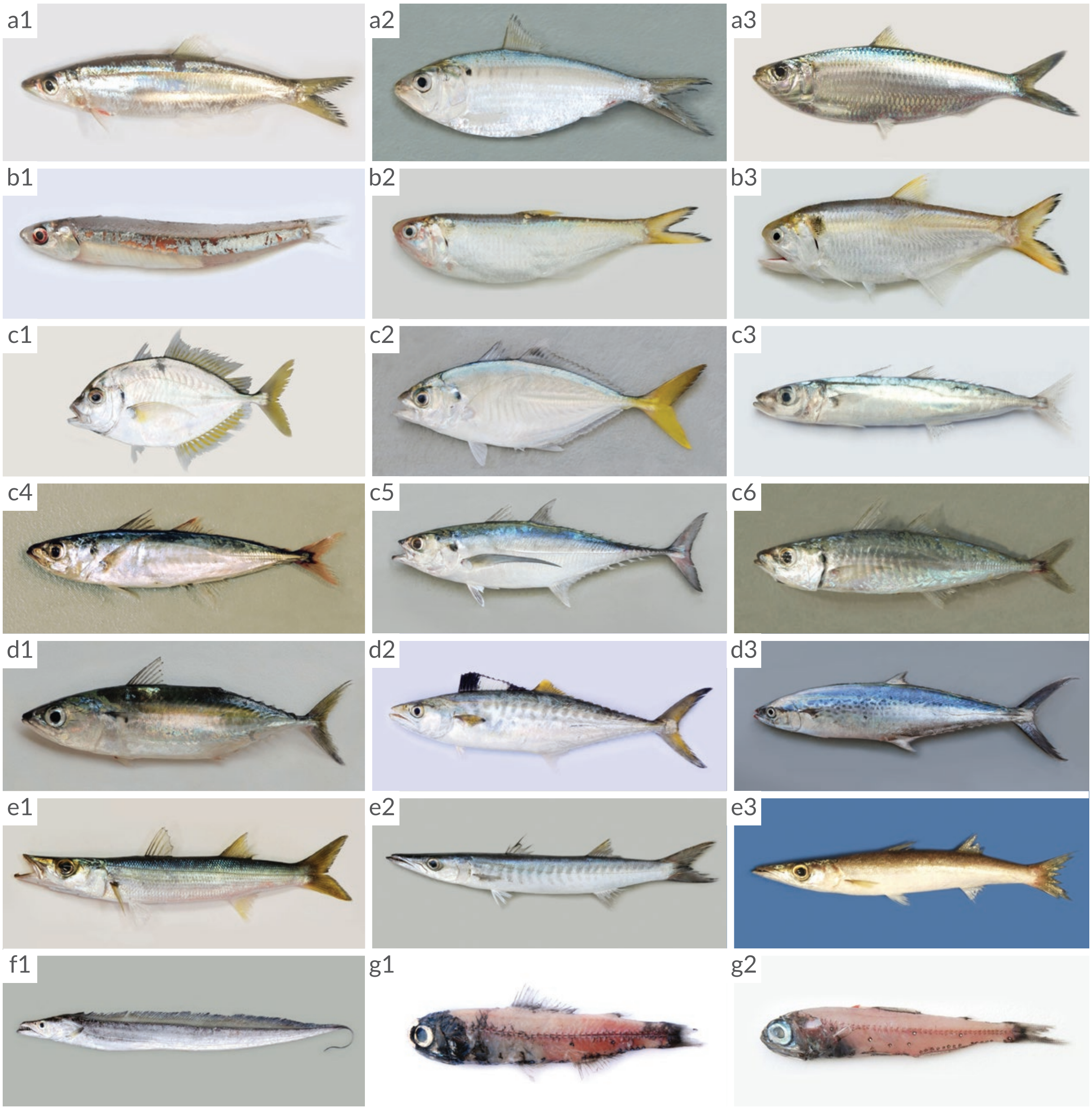

Figure 6.1 Some examples of common pelagic fish species in the Western Indian Ocean grouped by family. Species category PEL1 comprise of a) Clupeidae and b) Engraulidae and species category PEL2 comprise of c) Carangidae, d) Scombridae, e) Sphyraenidae and f) Trichiuridae. Myctophidae g) remains a separate acoustic category:

a) Clupeidae: a1. *Dussumieria acuta;* a2. *Hilsa kelee;* a3. *Sardinella gibbosa.*

b) Engraulidae: b1. *Stolephorus indicus;* b2.*Thryssa vitirostris;* b3. *Thryssa setirostris.*

c) Carangidae: c1. *Carangoides malabaricus;* c2. *Alepes djedaba;* c3. *Decapterus macrosoma;* c4. *Decapterus kurroides;* c5. *Megalaspis cordyla;* c6. *Decapterus russelli.*

d) Scombridae: d1. *Rastrelliger kanagurta;* d2. *Scomberomorus plurilineatus;* d3. *Scomberomorus guttatus.*

e) Sphyraenidae: e1. *Sphyraena obtusata;* e2. *Sphyraena putnamae;* e3. *Sphyraena acutipinnis.*

f) Trichiuridae: f1. *Trichiurus lepturus.*

g) Myctophidae: g1. *Diaphus effulgens;* g2. *Symbolophorus evermanni.*

Mozambique), to provide biomass estimates based on both survey methods. These surveys reported average catches of pelagic fish in kg/h from bottom trawls, in addition to the acoustic estimates. Catch rates based on swept area surveys have been used to determine the proportional composition of pelagic species in bottom trawls, and to compare catch rates of pelagic species to those of demersal species.

Acoustic instrumentation

Echo integration instruments used in fisheries research has changed considerably since its introduction in the late 1960s, to satisfy the quest for ever more accurate measurements of fish density (see Appendix 6.1). Analog equipment was initially used on the *Nansen* (1970s and early 1980s), and the integrator values (energy reflected by fish and other items in the water column) were recorded manually on paper. Already at that time, the *Nansen* used two different sound frequencies for fish detection. The echo signals and integrator values were later processed and recorded digitally, and after 1991, whole echograms were stored digitally in computer files. With the change-over to the second *Nansen* in 1994, further advances included four operating frequencies and a drop keel, to avoid the effects of bubbles under the hull of the vessel on data recordings. The interpretation of acoustic data also progressed, from manual scrutiny of black and white prints, to colour prints, and to successive stages of software developed to aid with interpretation of echograms and data on computer screens. Whereas acoustic methodology has remained conceptually much the same, the technological advances have gradually improved the accuracy of estimates.

Findings from the pre-digital phase are still of a high quality and valuable, with the information reflecting the exploration of new geographical areas. The pre-digital data likely underestimate fish abundance in the early period (before 1984), because instruments became electronically saturated in areas of high fish densities. Likewise, early calibration techniques of the echosounder instrumentation were less precise than the sphere calibration method introduced in the early 1980s and used today. The early abundance estimates may have been affected, as a result.

Target identification by trawling

Targeted trawling on acoustically observed fish schools are routinely carried out to obtain representative samples of catch composition, such as species type and body size. Either pelagic or demersal trawl gear can be used, depending on circumstance. At water depths of less than 30 m, the bottom trawl net is often used as a pelagic trawl, by attaching floats to the headline with 5–15 m long ropes to keep the trawl close to the surface. Once the fish are on board, they are sorted by species, and the total number and weight per species determined. The body lengths of samples of target species are measured, to estimate the size distribution of the fish school. Individual fish species or size classes have different escape success when confronted by trawl nets, which may introduce bias in measurements (see Slotte *et al*., 2007). Furthermore, several different pelagic trawl nets, with different selectivity properties, have been used on the *Nansen* (see Appendix 6.2). Axelsen and Johnsen (2015) described the factors that affect the selectivity of bottom trawl surveys undertaken by the second *Nansen*.

Spatio-temporal coverage of surveys

An underlying assumption of pelagic surveys is that the whole stock distribution area is covered in each survey. This is not always possible, because pelagic fish stocks are generally widely distributed and migratory, with movements and distribution patterns affected by seasons, availability of food and spawning behaviour. In the early days of acoustic surveys, the main goal of the Nansen Programme was to identify new fisheries resources – hence it had a broad geographical focus, and surveyed the waters of several countries consecutively. During this period, stocks with a regional distribution were often surveyed across their entire range for the first time in history.

Later, the focus shifted gradually to individual countries, with surveys coupled to Norwegian bilateral aid programmes. Several surveys were carried out on the same stocks in a single year, but restricted to national waters. This provided good information on seasonal distribution and abundance patterns, but the abundance of fish stocks extending beyond the surveyed area remained unknown. In Phase 4 (2006–2016), the focus moved back to a more regional approach, with surveys covering Large Marine Ecosystems (LMEs) (see Chapter 3). Whereas the regional approach improves spatial coverage and reduces bias, surveys still cannot quantify fish stocks found in waters less than 20 m deep, which is too shallow for the *Nansen* to work in.

Any review of *Nansen* surveys should therefore take into account that spatial coverage differed, between regions and over time, and that technological advances over the past 40 years have improved the accuracy of readings. Furthermore, the knowledge base has changed considerably since 1975, as has the context of the surveys and the research questions posed. Today's *Nansen* is much better equipped to survey pelagic fish stocks, but several classical challenges remain, highlighted below.

6.3 Results

Two time periods have been considered – exploratory surveys between 1975 and 1990; and ecosystem surveys between 2007 and 2014. No surveys were conducted in the Western Indian Ocean between 1991 and 2006. Locations referred to in the text are shown in Figure 6.2. A full overview of all surveys carried out can be found in Chapter 3.

Somali Coast subregion

Surveys in the Somali Coast subregion were restricted to the exploratory period (1975, 1976 and 1984) and covered the Somali east coast,

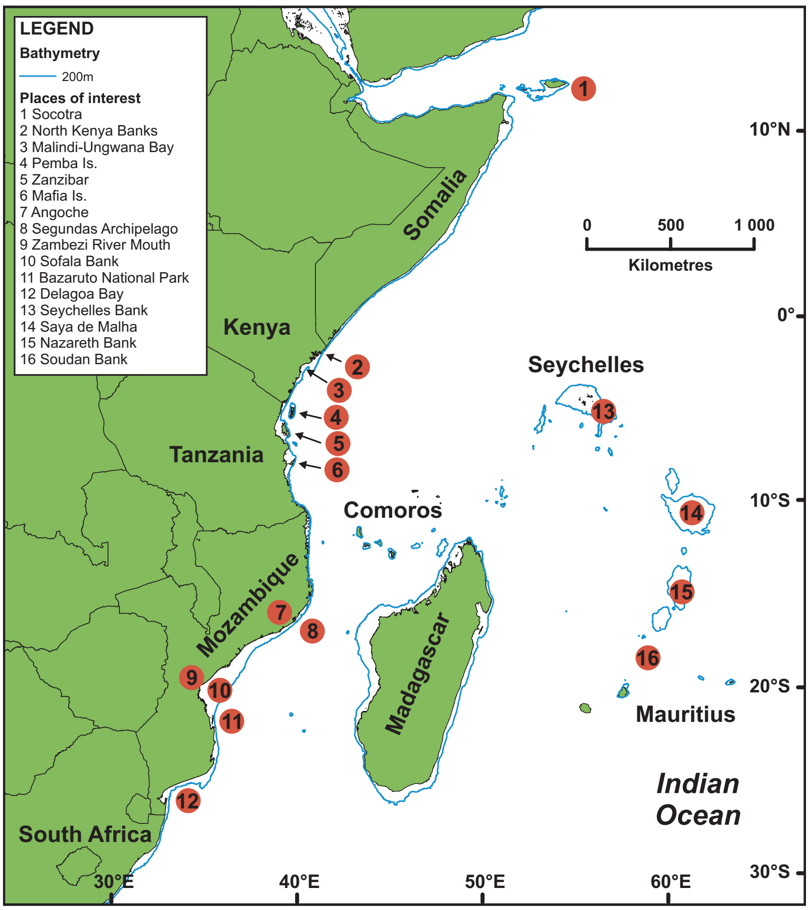

Figure 6.2. Geographic locations of islands, bays, banks and seamounts of the Western Indian Ocean, as mentioned in the narrative.

Socotra, and Somali north coast during the Northeast Monsoon (NE monsoon; December–March) and Southwest Monsoon (SW monsoon; July–September) seasons. Mesopelagic- (see Box 6.1) and small pelagic fish were the main catch, dominated by species with commercial potential, especially clupeids *Sardinella longiceps* and *Etrumeus teres*, engraulids *Engraulis japonicus* and *Stolephorus* spp. and scombrids *Scomber japonicus* (but probably *S. australasicus*) and *Scomberomorus commerson*. Clupeids were caught in 85 percent of 13 trawls in 1975 and 1976, and made up 50 percent of the total weight; engraulids were caught in 8 percent of trawls, making up 11 percent by weight; and scombrids were caught in 31 percent of trawls making up 39 percent by weight. Individuals of these species were found to be smaller and immature during the SW monsoon survey, compared to larger and mature during the NE monsoon survey. Schools were commonly mixed with the non-commercial porcupine fish (*Diodon maculifer*) and cardinal fish (*Synagrops* sp.) during the SW monsoon season.

Original acoustic biomass estimates from the 1970s were affected by saturation, and were therefore adjusted by 3 decibel (db) in 1984, effectively doubling the original estimates (Sætersdal *et al*., 1999). Concentrations of small pelagic fish were detected along the Somali Coast, with an average biomass of 1 million tonnes after adjustments. Fish densities were particularly high along the Somali east coast (Kesteven *et al*., 1981), and mackerel (identified as *Scomber japonicus* but most probably *Scomber australasicus*) were observed in relatively high quantities. Schools of this species showed a bentho-pelagic behaviour and were taken with the bottom trawl during the day, while appearing at night as a pelagic scattering layer at 150–200 m depth (Kesteven *et al*., 1981). Pelagic abundance estimates were considerably lower along the Socotra and north Somali coasts and these resources were therefore considered to be of lower commercial value.

The 1984 surveys off northeast Somalia covered the NE monsoon and SW monsoon seasons, respectively. Only the acoustic biomass from the first survey (245 000 tonnes pelagic fish) was considered reliable (Sætersdal *et al*., 1999). This estimate was substantially lower than in 1975 and 1976. Species composition included clupeids (*Dussumieria acuta*, *Etrumeus teres*, and *Sardinella longiceps*), carangids (*Decapterus macrosoma* and *D. russelli*), and a few *Scomber* spp. individuals.

East Africa Coastal Current (EACC) subregion

Four surveys were conducted off Kenya, and three off Tanzania, between 1980 and 1983. Surveys in Kenya covered the North Kenya Bank, Malindi-Ungwana Bay, and southern Kenya (shelf area of 4 245 nm^2; 10–500 m depth). Survey results were described in cruise reports (IMR, 1982d; Nakken, 1981; Iversen, 1983) and summarized in special reports by Iversen (1984) and Iversen and Myklevoll (1984a). In Tanzania, pelagic trawls were conducted at Pemba, Zanzibar, Mafia and southern Tanzania (13 500 nm^2; 10–500 m depth) with results described in cruise reports (Myklevoll, 1982; IMR, 1982a, 1983) and special reports (Iversen and Myklevoll, 1984b; Iversen *et al*., 1984).

The surveys showed low abundance of pelagic fish but high species diversity. At least 260 fish species were identified in Kenya (Sætersdal *et al*., 1999). Two expert taxonomists participated in the surveys, and their findings underlined the need for taxonomic support during surveys – this gave rise to a stronger focus on taxonomy within the Nansen Programme. The EACC subregion was characterized by scattered aggregations of pelagic fish, and in Kenya, these were confined to Malindi-Ungwana Bay. The pelagic fish biomass from echo integration was lower in Kenya (mean of 25 250 tonnes) than in Tanzania (74 700 tonnes).

The clupeids were the most speciose (*Pellona ditchela*, *Sardinella gibbosa*, *Ilisha melastoma*, *Dussumieria acuta*). Other pelagic fish families included carangids (*Decapterus russelli*, *D. kurroides*, *Atule mate*, *Carangoides* spp.), scombrids (*Rastrelliger kanagurta*, *Scomberomorus commerson*), sphyraenids (*Sphyraena forsteri*, *S. putnamiae*, *S. obtusata*) and engraulids (*Thryssa vitrirostris*, *Stolephorus commersonii*). The estimated pelagic fish biomass of the EACC subregion included semi-pelagic ponyfish (*Leiognathus* spp.). Based on the Kenya surveys, it was concluded that the pelagic fish resources would not be able to support the planned development of industrial fisheries. The Tanzania surveys suggested that the present yield of about 40 000 tonnes could potentially be increased slightly, if fishing areas were extended beyond the fringing reefs. Low fish densities and predominance of ponyfish limited fisheries potential (Iversen, 1984; Iversen *et al*., 1984).

Mozambique subregion

Several surveys were carried out in Mozambique between 1975 and 1983, to explore pelagic and demersal fish resources using acoustic methods in combination with bottom trawl surveys (see Chapter 7). Survey results are described in cruise reports (IMR, 1977, 1978a, b), and summary reports (Sætre and Paula e Silva, 1979; Brinca *et al*., 1981, 1983). Two pelagic surveys were also conducted in 1990 (IMR, 1990a, b).

The first survey period (1977–1978) covered the entire Mozambique coast in four trips, but the acoustic abundance estimate was considered unreliable and is not reported further. The later surveys, up to 1990, covered the Sofala Bank, and in some cases also Delagoa Bay. Biomass estimates ranged between 100 000 and 210 000 tonnes of pelagic fish – note, however, that estimates are not all directly comparable, because the surveys covered different areas. On the Sofala Bank, the highest biomass occurred inshore, around 50 m depth. The *Nansen* could not survey waters shallower than 20 m, and pelagic fish abundance shallower than this depth therefore remained unsampled.

Most bottom and pelagic trawls were carried out in 1982 and 1990, and Sætersdal *et al*. (1999) considered these data to represent species composition and distribution well. Carangids were most frequently encountered, followed by clupeids and engraulids. A high abundance of anchovy (*Stolophorus* spp.) was found in the 1977, 1978 and 1983 surveys, however the biomass of short-lived fish species fluctuated widely, and they were not abundant in 1982, nor in 1990.

After an absence of 17 years, the second RV *Dr Fridtjof Nansen* carried out an ecosystem survey in Mozambique in 2007 (Johnsen *et al*., 2007). As part of the survey, pelagic resources between 20 and 1 000 m depth were assessed in three survey regions: south (South African border to 21°30'S); central (21°30'S–17°15'S, including Sofala Bank); and north (17°15'S to Tanzanian border). The trawl catches were further separated into inner shelf (20–50 m depth), outer shelf (50–200 m) and deep slope stations (200–800 m).

Acoustic results indicated low to medium pelagic fish densities over most of the shelf, and much lower than in surveys undertaken 17 years before. Mesopelagic fish species were common in the water column beyond the shelf break. The estimated acoustic biomass for clupeids (PEL1) was 20 000 tonnes in the central and south regions combined, while the biomass of carangids, sphyraenids, trichiurids and scombrids (PEL2) was 34 000 tonnes. Clupeid biomass was particularly low in the south, and between Beira and Angoche.

The 2007 ecosystem survey undertook 115 bottom trawls, but only 4 pelagic trawls. Trawl catches were used to compare species composition by region. In the south (inner shelf), pelagic fishes made up 65 percent of the total catch weight, similar to early surveys. Carangids were the most common (48 percent) followed by sphyraenids (15 percent). Further from the coast pelagic fishes made up 55 percent of the bottom trawl catch weight on the outer shelf, again mainly carangids (18 percent) followed by sphyraenids (4 percent). In deeper water than this (deep slope) pelagic fishes contributed less than 1 percent of the total catch.

In the central region (Sofala Bank) pelagic fishes contributed 31 percent of the total catch on the inner shelf, 37 percent on the outer shelf, and again, almost nothing on the deeper slope. Clupeids were the most abundant (18 percent) over the inner shelf, followed by carangids (8 percent), trichiurids (4 percent), sphyraenids (3 percent) and scombrids (2 percent), respectively. Carangids were most abundant on the outer shelf (35 percent). The northern region of Mozambique, up to the border with Tanzania, has a very different habitat than the rest of the coast. This coast is dominated by coral reef systems and deep trenches. In this region, the mean pelagic fish catch contributed only 1.8 percent to the total weight caught in bottom trawls.

A detailed study using bottom trawls at selected locations along the Mozambique coast, as part of the 2007 survey, found high variability of pelagic fish catch rates. At the Segundas Archipelago (central-north Mozambique) catch rates of pelagic fishes were low (7.7 kg/h), whereas those at the Zambezi River mouth were two orders of magnitude higher (761 kg/h and 77 percent of total catch volume). Catch rates were 680 kg/h for clupeids, 74 kg/h for carangids, and 5 kg/h for sphyraenids. At Bazaruto National Park, the mean catch rate for pelagics was 10 kg/h, including carangids (3 percent) and scombrids (2 percent). These variations are linked to the availability of food for pelagic species. The Zambezi River, for example, brings vast amounts of nutrients to the sea, and is responsible for enhancing nearby primary and secondary production. Higher productivity in the vicinity of the plume creates favorable feeding conditions for pelagic species.

A 2008 survey focused on process studies associated with eddies in the Mozambique Channel (Kaehler *et al*., 2008). The survey focussed on deeper offshore waters, and no small pelagic fish were observed – apart from some mesopelagic species. A 2009 ecosystem survey in northern Mozambique (Olsen *et al*., 2009) focussed on pelagic resources, and reported biomass values of 15 000 tonnes (PEL1) and 40 000 tonnes (PEL2).

A 2014 ecosystem survey, similar to the one conducted in 2007 (see above), covered the south and central regions (Krakstad *et al*., 2015). In the south, acoustic abundance of PEL1 was 6 000 tonnes, and trawl catches showed that clupeids contributed 63 percent and engraulids 37 percent. PEL2 families were common between 20 and 50 m depth, but at low densities. Their acoustic abundance estimate was 21 000 tonnes, with carangids contributing 70 percent to trawl catch weight. Bottom trawls in the south caught 53 percent pelagic species (by weight) on the inner shelf, 16 percent on the outer shelf and 4 percent on the deep slope.

In the central region (Sofala Bank), acoustic abundance of PEL1 was only 9 400 tonnes, compared to traditionally much higher abundance values in the past. Clupeid species were mainly *Sardinella albella*, *Encrasicholina punctifer*, *Thryssa vitrirostris* and *Pelona ditchela*. PEL2 species were recorded across most of the Bazaruto shelf between 20 and 100 m depth, generally at low densities. The acoustic abundance estimate of 46 000 tonnes comprised mainly *Decapterus russelli*, *Decapterus macrosoma*, *Selar crumenophthalmus*, *Carangoides malabaricus*, *Trichiurus lepturus* and *Scomberomorus commerson*. Swept area estimates of pelagic fish biomass (usually biased downwards) showed remarkably similar results to the 2007 survey, with carangids dominating and a total pelagic biomass of around 42 000 tonnes.

Mascarene subregion

A single acoustic survey around Seychelles in 1978 found pelagic fish scattered over most of the main bank. Trawl catch rates of carangids averaged 1 083 kg/h, mostly *Decapterus maruadsi* and *D. macrosoma*. Small-sized individuals (3.5–15 cm) were sampled off the Mahé Plateau, suggesting a nursery area for this genus.

Two ecosystem surveys in 2008 focussed on process studies on the offshore banks between Mauritius and Seychelles (Strømme *et al*., 2009). Acoustic estimates of mesopelagic fishes found a low abundance towards the south (north coast of Mauritius and around Nazareth Bank) but higher densities in the north, around Saya de Malha and Seychelles Bank, and in the wide channel between them. The highest recordings were associated with the margins of the banks. No commercially viable densities of pelagic fish were observed, but PEL2 species were thinly scattered over shallow parts of Nazareth Bank, with low-density aggregations on the northern Saya de Malha and the southwestern edges of Seychelles Bank.

The 2010 survey of the pelagic resources of Mauritius covered the shelf and slope to about 1 000 m bottom depth (Strømme *et al*., 2010). Continuous acoustic recording and analysis throughout the survey of the narrow shelf around Mauritius, and the banks and plateau further north, found no aggregations of PEL1 species, and PEL2 species were absent from the southern part between Mauritius and Soudan Bank.

A low-density aggregation of PEL2 species formed around 15°30'S on the western side of the plateau, in a similar location as observed during 2008. This area appears to be more productive than the generally oligotrophic upper pelagic ecosystem of the Mascarene Plateau. The abundance of pelagic fish was assessed at 6 000 tonnes (PEL2) located at Nazareth Bank.

Madagascar and Comoros subregion

A 1983 *Nansen* survey relied on acoustic recordings, demersal and pelagic trawls to determine the composition and abundance of fish resources at depths of 20 to 200 m in three areas: south coast (south of 25 °S); southeast coast (25–22 °S), and; northeast coast (22–17 °S). The mean catch rate varied by area, and pelagic biomass along the south and east coasts was estimated at 50 000 tonnes, with carangids, clupeids, engraulids, scombrids, leiognathids and sphyraenids the most common families.

The first ecosystem survey of Madagascar took place 25 years later, in 2008, along the south and east coasts. The focus was on physical processes and acoustic assessment of pelagic fish resources (Krakstad *et al*., 2008). Biomass estimation was carried out in the same three shelf areas, with some adjustments (i.e. southeast coast, 25–20 °S and northeast coast, 20–12 °S). Biomass estimates of PEL1 and PEL2 species groups were uncertain, because pelagic fish were found close to the seafloor. The seafloor along much of the coastline was unsuitable for bottom trawling, thus complicating accurate species identification. In the south, PEL1 species were found in two small low density areas with a total biomass of 15 000 tonnes.

The most common pelagic species were *Engraulis japonicus*, with small quantities of *Sardinella gibbosa* and *Etrumeus teres* also found. The PEL2 species were also distributed in two low density areas on the south shelf, with a continuous low density on the southeast shelf, up to 20 °S. The biomass estimate for the south coast was 54 000 tonnes, with approximately 9 000 tonnes and 14 000 tonnes estimated for the southeast and northeast coasts, respectively. The most abundant PEL2 species were *Trachurus delagoa* and *Decapterus macrosoma*.

An ecosystem survey of western Madagascar in 2009 covered the south coast (south of 25 °S); southwest coast (25–20 °S) and northwest coast (20–12 °S). The survey area overlapped with the 2008 survey area in the south. The 2009 survey estimated a biomass of 30 500 tonnes of pelagic fish (2 500 tonnes PEL1 and 28 000 tonnes PEL2 species) compared to 54 000 tonnes in 2008. Even though some differences in areas covered in 2008 and 2009 may affect estimates, both PEL1 and PEL2 groups covered smaller distribution ranges at lower densities in 2009 than in 2008. Almost no pelagic fish were registered acoustically or caught in trawl nets along the southwest coast, up to 20 °S. The cruise report from the survey suggests that pelagic fishes were distributed inshore of the area surveyed (Alvheim *et al*., 2009).

In the northwest, two small, low density areas (0–300 s_A) of PEL1 were observed, with *Herklotsichthys quadrimaculatus* the most common species. PEL2 were observed in low densities, and among them, the carangid *Selar crumenophthalmus* occurred in small numbers in most samples. The most abundant species was *Carangoides caeruleopinnatus*, but not in large numbers. The highest catches were of *Carangoides fulvoguttatus*, *Caranx speciosus* and *Decapterus kurroides*, caught in a few hauls. Two species of barracuda were common, *Sphyraena forsteri* and *S. helleri*. The most common scombrid was *Scomberomorus commerson*.

The low pelagic fish biomass estimates from the west coast of Madagascar is likely a result of a reef-like ridge extending northwards along the coast, making most of the shelf inaccessible to the *Nansen*. As in other areas, pelagic fishes are expected to be far more abundant over the shelf, than in the offshore waters that were accessible to the *Nansen*.

The Comoros gyre was surveyed acoustically and with mid-water trawls in 2009 (Roman *et al*., 2009). Pelagic fish schools were sparse, however strong scatterings of mesopelagic fish were recorded over the slope and deep water around all the islands. In general, the acoustic values were low across the whole survey area, indicating low pelagic fish abundance, despite high numbers and species diversity of larval fish.

6.4 Regional patterns in pelagic fish biomass

Pelagic fish is an important component of many shelf ecosystems worldwide. In systems with high primary production, there are often few pelagic species, but with very high biomass, as is the case with the Peruvian anchovy, or the anchovy and sardine on the southwest African coast. In oligotrophic systems, such as most of the tropical Western Indian Ocean (apart from upwelling areas in Somalia), pelagic fish still dominate on the shelf, but with lower abundance because of lower food availability. Species diversity typically increases in oligotrophic waters because greater competition for limited food resources stimulate species diversification, but limit the abundance of each individual species (Valiela, 1995).

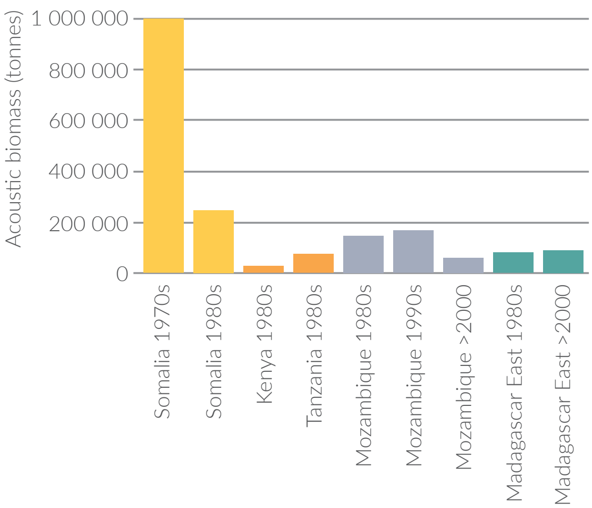

Figure 6.3 Time series of acoustic estimates from the Western Indian Ocean surveys, averaged by subregion and decade. Note that survey to survey variation is not captured by the Figure. For detailed estimates, see Sætersdal *et al.* (1999).

A time series of acoustic estimates from the Western Indian Ocean surveys, averaged by subregion and decade, show much higher pelagic fish biomass in the Somali subregion during the 1970s, than anywhere else in the Western Indian Ocean (Figure 6.3). The high pelagic biomass off Somalia was not surprising, because it is a well-known upwelling region with high primary productivity, and hence food for small- and mesopelagic fishes. Biomass in this subregion was lower during the 1980s, when it was based on partial coverage of the coastline only. Pelagic fish biomass was lowest in the tropical EACC subregion (Kenya and Tanzania), which is characterized by warm, relatively stable and stratified tropical waters (Chapter 4). Primary productivity is generally low (Chapter 5), resulting in lower pelagic fish biomass (Figure 6.3).

Towards the southern part of the Western Indian Ocean (Mozambique), larger river outlets, turbulent oceanic eddy systems and stronger wind fields mix nutrients into the surface layers, thus increasing primary productivity and pelagic fish abundance. Wind-driven upwelling and enhanced primary productivity along the south and southeast Madagascar coast also support higher pelagic fish abundance.

Spatial trends by family

Data from all *Nansen* trawl catches made in the Western Indian Ocean (including both demersal and pelagic trawls) were obtained from the Nansis database and standardized to kg/h. The data showed a high diversity of pelagic fish species across the region, but especially in the EACC subregion. Six families formed the bulk of the pelagic fish resources: carangids, clupeids,

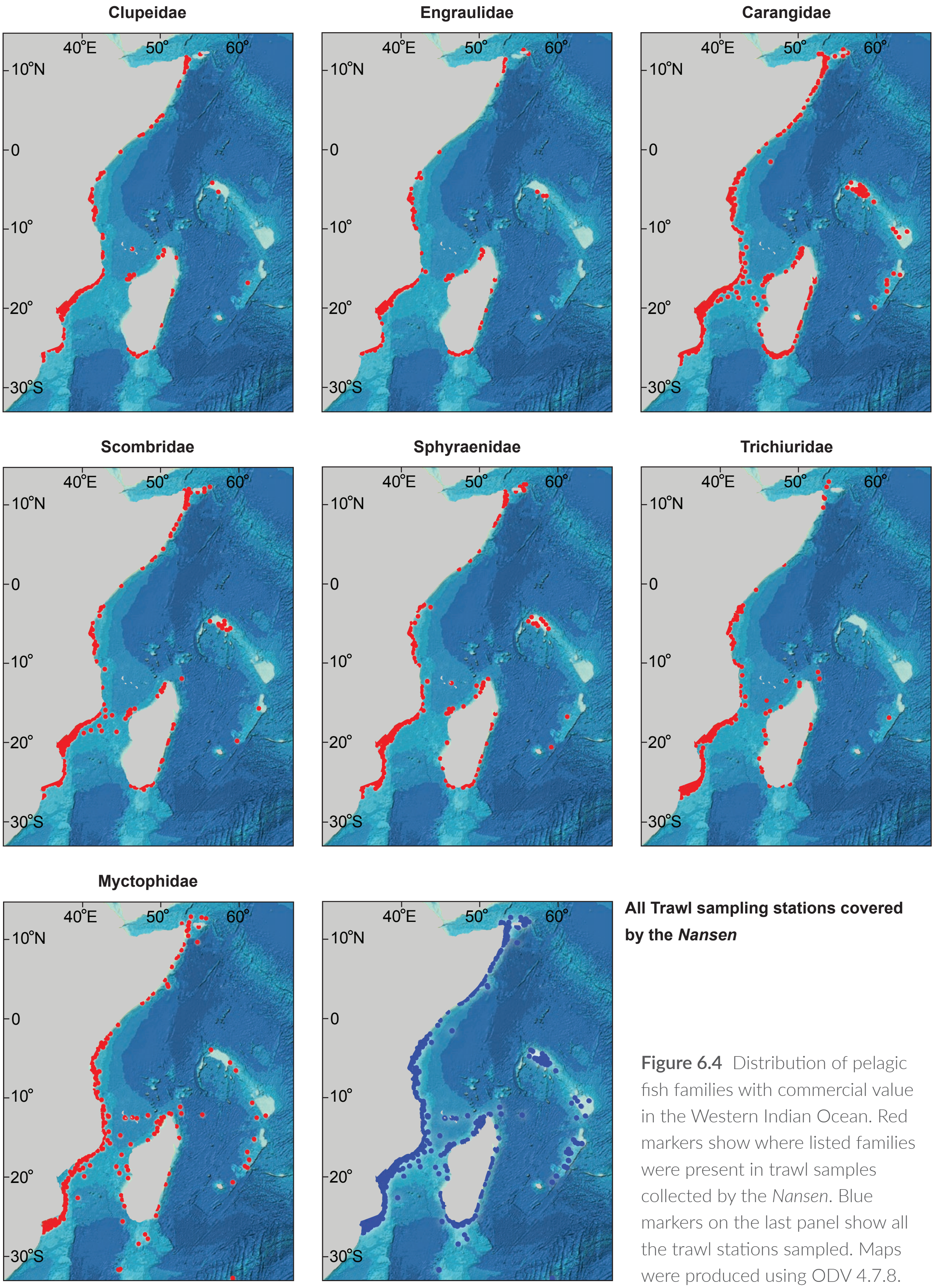

Figure 6.4 Distribution of pelagic fish families with commercial value in the Western Indian Ocean. Red markers show where listed families were present in trawl samples collected by the *Nansen*. Blue markers on the last panel show all the trawl stations sampled. Maps were produced using ODV 4.7.8.

engraulids, scombrids, sphyraenids and trichiurids. Mesopelagic fishes (several families) were also important.

Carangids are probably the most widely distributed family in the region. It is found in shallow shelf areas, from the Horn of Africa, along the coast to the Mozambique Channel, and around Madagascar, Mauritius, the Mascarene Plateau, and the Seychelles (Figure 6.4). Clupeids showed a similar distribution, but also occurred in shallow shelf areas around the Comoros. Engraulids were more abundant in the southern part of the EACC, Mozambique Channel, and northwest, east and south of Madagascar. Scombrids, sphyraenids and trichiurids had similar distribution throughout the region, but with higher densities of scombrids near the horn, and higher densities of sphyraenids and trichiurids in parts of the Mozambique Channel. The latter three families were distributed over the shallow shelf areas of both mainland and island coasts. Myctophids (mesopelagics) were widely distributed throughout the Western Indian Ocean, but high densities occurred only off the Horn of Africa (Figure 6.4). Dominant species within each pelagic fish family differed across the region. Species with the highest biomass, based on data from all *Nansen* surveys, are shown in Appendix 6.3.

Temporal trends by family

Comparisons between the surveys undertaken in the Western Indian Ocean by the first *Nansen* (1975–1990) and the second *Nansen* (2007–2014) are restricted to Madagascar and Mozambique, because only these two countries were covered in both periods, with similar survey types. The south and east coasts of Madagascar were surveyed in June 1983 (Sætre *et al*., 1983) and in late August 2008 (Krakstad *et al*., 2008). Both surveys covered the shelf at less than 200 m depth, with combined acoustic and swept area surveys of similar design. In 1983, fish biomass was estimated at roughly 85 000 tonnes, of which about 60 percent were pelagic fishes (51 000 tonnes). In 2008, with more advanced acoustic equipment, and presumably a more accurate estimate, pelagic fish biomass was estimated at 92 000 tonnes, of which 16 percent were clupeids, and the rest mainly carangids.

Both surveys found highest pelagic fish densities on the south coast, but scattered concentrations along the east coast. In both surveys *Trachurus delagoa* and *Decapterus macrosoma* were the most

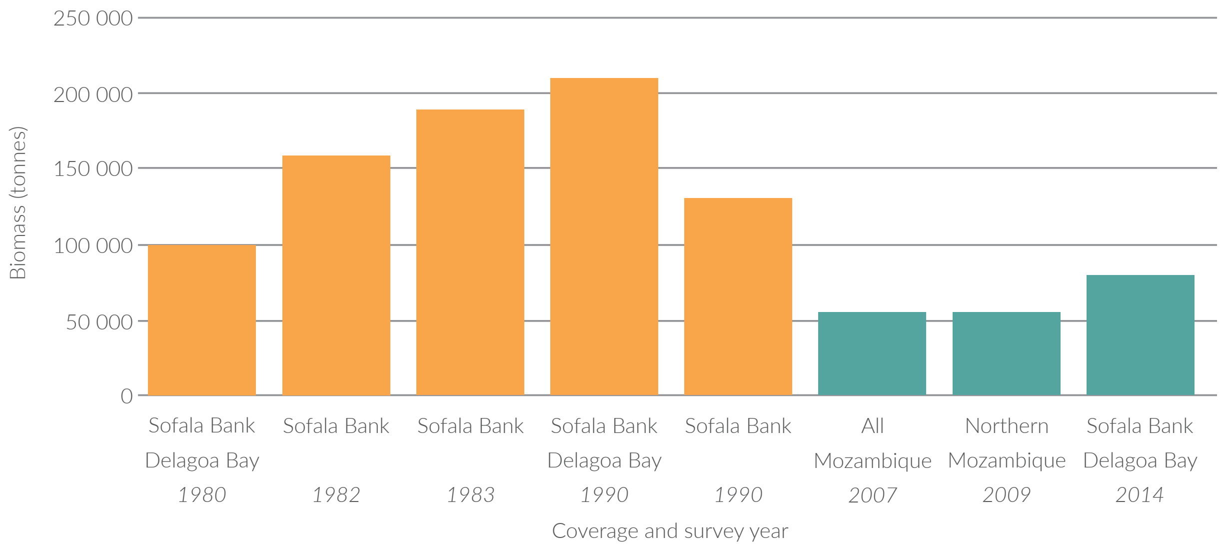

Figure 6.5 Acoustic biomass estimates off Mozambique, based on surveys with the first (orange) and second (green) RV *Dr Fridtjof Nansen*. Estimates are not directly comparable, because survey areas were inconsistent. Nevertheless, the biomass change over time is striking.

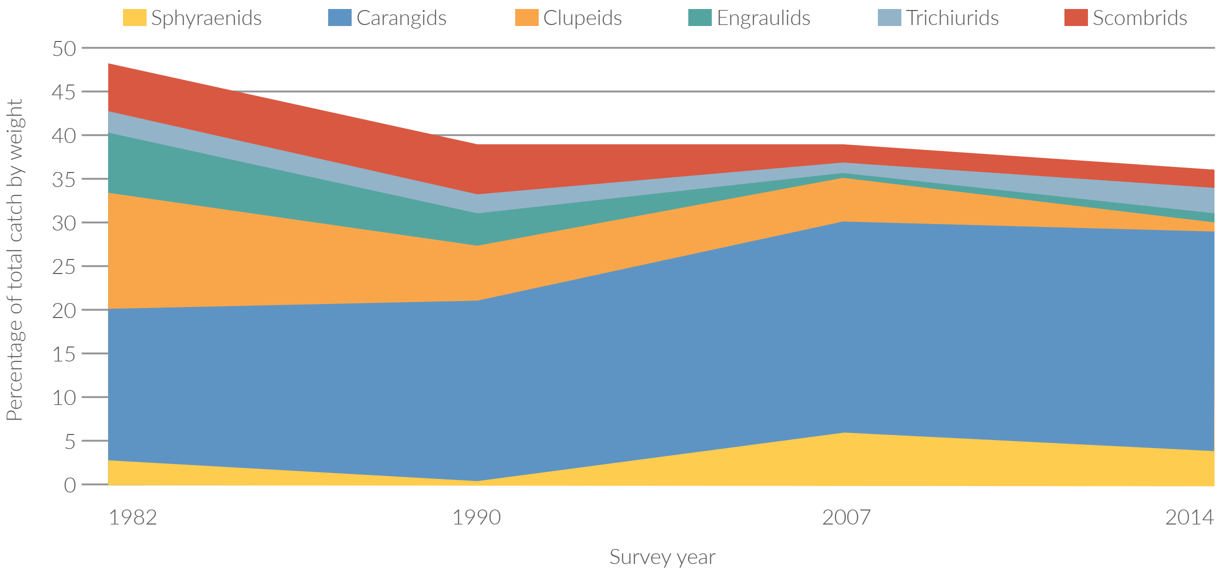

Figure 6.6 Percentage contribution of main pelagic species groups in Mozambique, based on total catch by weight from valid bottom trawl hauls between 15 and 100 m bottom depth in four selected surveys.

abundant pelagic species in catches, and the leiognathids were most abundant in the central part of the east coast. Considering the improvement of acoustic instrumentation in the later period, no differences were found between surveys. These results suggest relatively stable pelagic fish abundance off south and east Madagascar, with species composition and main distribution areas also remaining similar after 25 years. Aside from the *Nansen* surveys very little other scientific information shedding light on the variability of the fish stocks on the south and east coast is available from Madagascar. Even catch records are sketchy. Further studies to investigate the abundance and diversity of fish in this region would be valuable.

More surveys were carried out in Mozambique, during both periods (pre-1990 and post-2006; Figure 6.5). During this period, coastal waters have been subjected to increasing artisanal and semi-industrial fishing. Historic evaluations suggested a pelagic MSY of 130 000 tonnes (McClanahan and Young, 1996), while an average pre-1990 acoustic biomass estimate for Sofala Bank was 158 000 tonnes. Of this, clupeids contributed about 58 000 tonnes and carangids and scombrids 100 000 tonnes (Sætersdal *et al*., 1999). The early estimates were, however, affected by high survey to survey variation in acoustic biomass estimates, ostensibly because of a combination of high natural variability in pelagic fish abundance, design of surveys and areal coverage, and limitations of acoustic equipment used at the time (Sætersdal *et al*., 1999).

In contrast, the two surveys carried out in Mozambique in 2007 and 2014 indicated considerably lower biomass levels. Estimates from the 2014 survey were 9 000 tonnes of clupeids and 46 000 tonnes of carangids and scombrids from the Sofala Bank. The 2007 survey indicated similar levels but did not report the biomass per region. The reduced clupeid biomass estimate is supported by sharply declining catch rates in the artisanal fishing fleet (Cardinale *et al*., 2014). Given that earlier estimates tended to underestimate biomass, the recent decline in the clupeid standing stock estimate on the Mozambique shelf is significant. For carangids, the decline in biomass was less, recent estimates being consistently lower than historic ones.

Catch composition of pelagic fish from four surveys in Mozambique (1982, 1990, 2007 and

2014) show reduced proportions of clupeids and engraulids in bottom trawls over time, and a slight increase in carangids (Figure 6.6). Changes in trawl equipment and increased catch efficiency after the change-over from the first to the second *Nansen* does not explain the variation in catch composition and quantities (Axelsen and Johnsen, 2015).

Another likely cause for the reduced biomass of clupeids, and especially engraulids, is a combination of fishing pressure and the effects of reduced primary productivity available for pelagic stock growth. These species are commonly found near the mouth of the Zambezi River. Three major dams were completed along this river since the beginning of the 1970s, with negative ecological effects on the lower delta (da Silva, 1986; Gammelsrød, 1992; Hoguane and Armando, 2015). A substantial reduction of the flood plain and reduced discharge of nutrients to shelf waters after 1975 have resulted in decreased shrimp and fish catches (Gammelsrød, 1992; Hoguane and Armando, 2015). In addition, the coast became more accessible, and fishing pressure escalated after the end of the civil war in 1992. The escalation in fishing pressure continues to the present day (Vølstad *et al*., 2014).

6.5 Conclusions

Echo-integration to detect and quantify fish schools, combined with trawling to determine the species and body size of fish in a school, are routine sampling activities on *Nansen* surveys. These methods have been used since the onset of *Nansen* surveys in 1975, and data are available for most of the Western Indian Ocean shelf, albeit collected irregularly over space and time. Major technological advances in echo-integration instruments, data processing and interpretation over the past 40 years have revolutionized the accuracy and range of acoustics – contemporary records are therefore not directly compatible with those collected by the first RV *Dr Fridtjof Nansen* during the 1970s and 1980s. Findings from the pre-digital phase are, however, still of a high quality and valuable, with the information reflecting the exploration of new geographical areas. The pre-digital data likely underestimate fish abundance in the early period (before 1984), because the instruments used at that time became electronically saturated in areas of high fish densities. In retrospect, the high (but underestimated) biomass values recorded in the past, compared to the lower (but more accurate) biomass estimates at present, suggest that some of the observed declines in pelagic fish resources, for example in Mozambique, have been more severe than what the numbers show. Conversely, pelagic fish stocks off southeast Madagascar have remained similar over time, in terms of species composition, distribution patterns and biomass.

Historical data from *Nansen* surveys comprise mainly biomass estimates, distribution maps of pelagic fish and species composition from trawl sampling. However, it lacks detailed information useful for investigating seasonal distribution patterns, feeding and spawning behaviour and nursery grounds. In general, clupeids spawn in the vicinity, (mainly down-current) of areas with enhanced primary production, such as near river outlets and local upwelling cells (especially off Somalia, but also in Mozambique and southern Madagascar). These productive areas often coincide with greater aggregations of pelagic fish in the historical data. Carangids have been observed to spawn in deeper waters, often at the shelf edge. Although seasonality in pelagic fish distribution and behaviour is clear from fisheries data (Fondo *et al*., 2014; Munga *et al*., 2015), the oceanographic drivers thereof remain unclear. Future surveys can address this important knowledge gap.

Commercially important small pelagic fish stocks are most likely shared between countries in the Western Indian Ocean, because of their movements across international boundaries. Regional surveys over large geographical areas are therefore required to identify seasonal migration and distribution patterns, and to define individual fish stocks. The third RV *Dr Fridtjof Nansen*, commissioned in 2017, is equipped with modern acoustic and trawl equipment, and it is therefore well-suited to undertaking such surveys. ■

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