The unfished target

Structure and Composition of mesopelagic fauna

Heino Fock, Thünen Institute

Problem statement :
A Dark Hole in Our Understanding of Marine Ecosystems and Their Services: Perspectives from the Mesopelagic Community.

- Provision of food resources
- Nutraceuticals
- Climate regulation → carbon sequestration through biological carbon pump
- Diversity

- **and they are the food of tunas and other apex predators**

St. John MA, et al. Front Mar Sci. 2016;3: 1–6.

The unfished target

Structure and Composition of mesopelagic fauna

Heino Fock, Thünen Institute

Implications for apex predators :

Box 1–Summary of major climate change effects and impacts on the trophodynamics of marine predators.

Climate change effects	Impacts and vulnerabilities to trophodynamics
• Ocean acidification • Temperature rise • Shoaling of mixed layer depth, oxygen minimum zones • Circulation changes (e.g. ENSO) • Biogeochemical feedback processes • Sea level rise	• Alterations to food chain length and complexity (energy transfer efficiency) • Decreased productivity • Biodiversity hotspots • Shifts and restrictions in population abundances and distributions • Alterations in species assemblages (food availability to higher order predators)

St. John MA, et al. Front Mar Sci. 2016;3: 1–6.
Young JW, et al. Deep Res Part II Top Stud Oceanogr. 2015;113: 170–187.

The unfished target

Structure and Composition of mesopelagic fauna

Heino Fock, Thünen Institute

Implications for apex predators, e.g. food chain length :

Oligotrophic

1. Picophytoplankton → Microzooplankton → Small Copepod → Carnivorous Zooplankton → Micronekton → Nekton

eutrophic

2. Microphytoplankton → Large Copepod / Euphausiid → Micro-nekton → Nekton

St. John MA, et al. Front Mar Sci. 2016;3: 1–6.
Young JW, et al. Deep Res Part II Top Stud Oceanogr. 2015;113: 170–187.

Mesopelagics – what are we talking about?

Mesopelagic fish are part of a group of organisms referred to as micronekton (besides jellyfishes and crustaceans),

- which generally range in size from 1 to 15 cm, with few exceeding 30 cm in size.
- They have a worldwide distribution, oceanic as well as pseudo oceanic (neritic zone), and encompass more than thirty described fish families.
- They inhabit the mesopelagic zone, generally described as the water column between 200 and 1 000m depth, and are found in one or more of several deep scattering layers during daytime and migrate at night to the surface (at least some)
- Staby A, Krakstad JO. 2008. BCLME project LMR/CF/03/08

<u>But we start with the „normal“ fisheries !</u>

I. Fisheries of the world & status of stocks : By statistical units

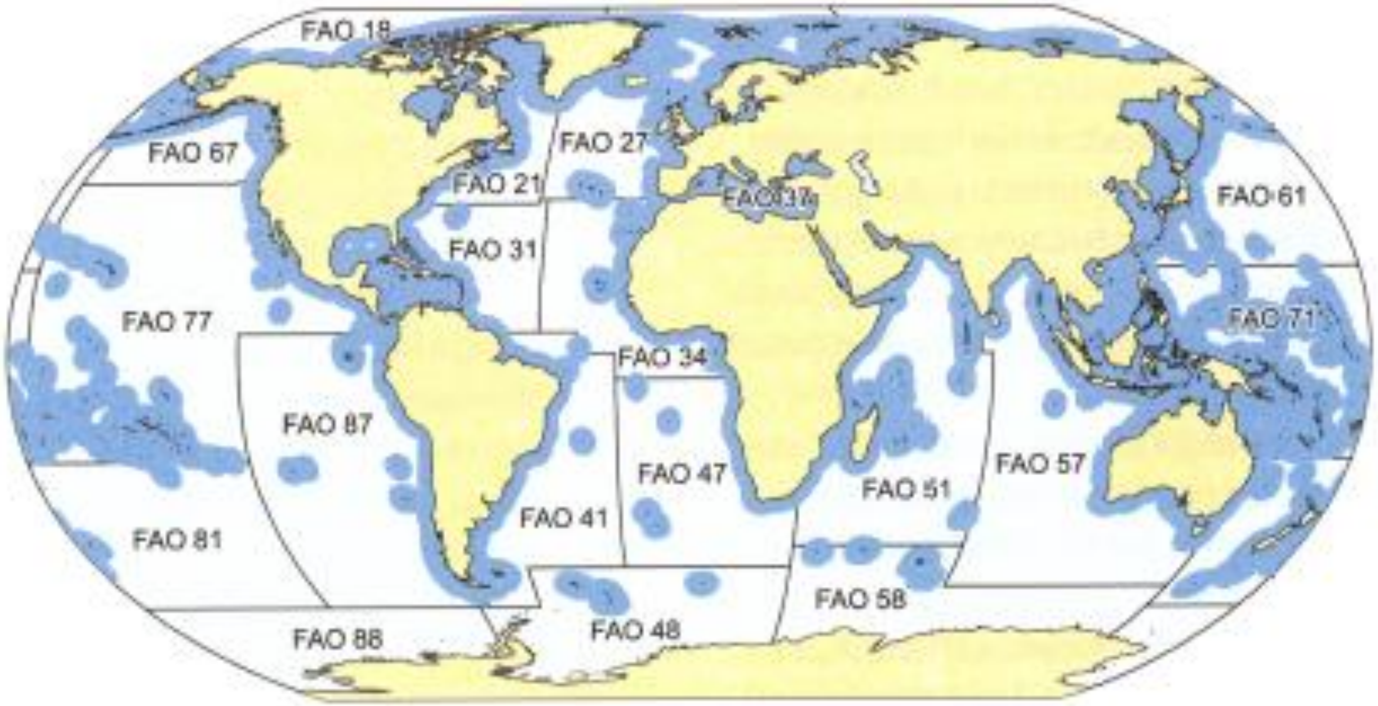


Figure 2.1. The extent and delimitation of countries' EEZs, as declared by individual countries or as defined by the *Sea Around Us* based on the fundamental principles outlined in UNCLOS (i.e., 200 nautical miles or midline rules), and the FAO statistical areas by which global catch statistics are reported. Note that for several FAO areas, some data exist by subareas as provided through regional organizations (e.g., International Council for the Exploration of the Sea [ICES] for FAO area 27). The *Sea Around Us* uses these spatially refined data to improve the spatial allocation of catch data, as described in chapter 5.

12 · CHAPTER 2

I. Fisheries of the world & status of stocks: By biome

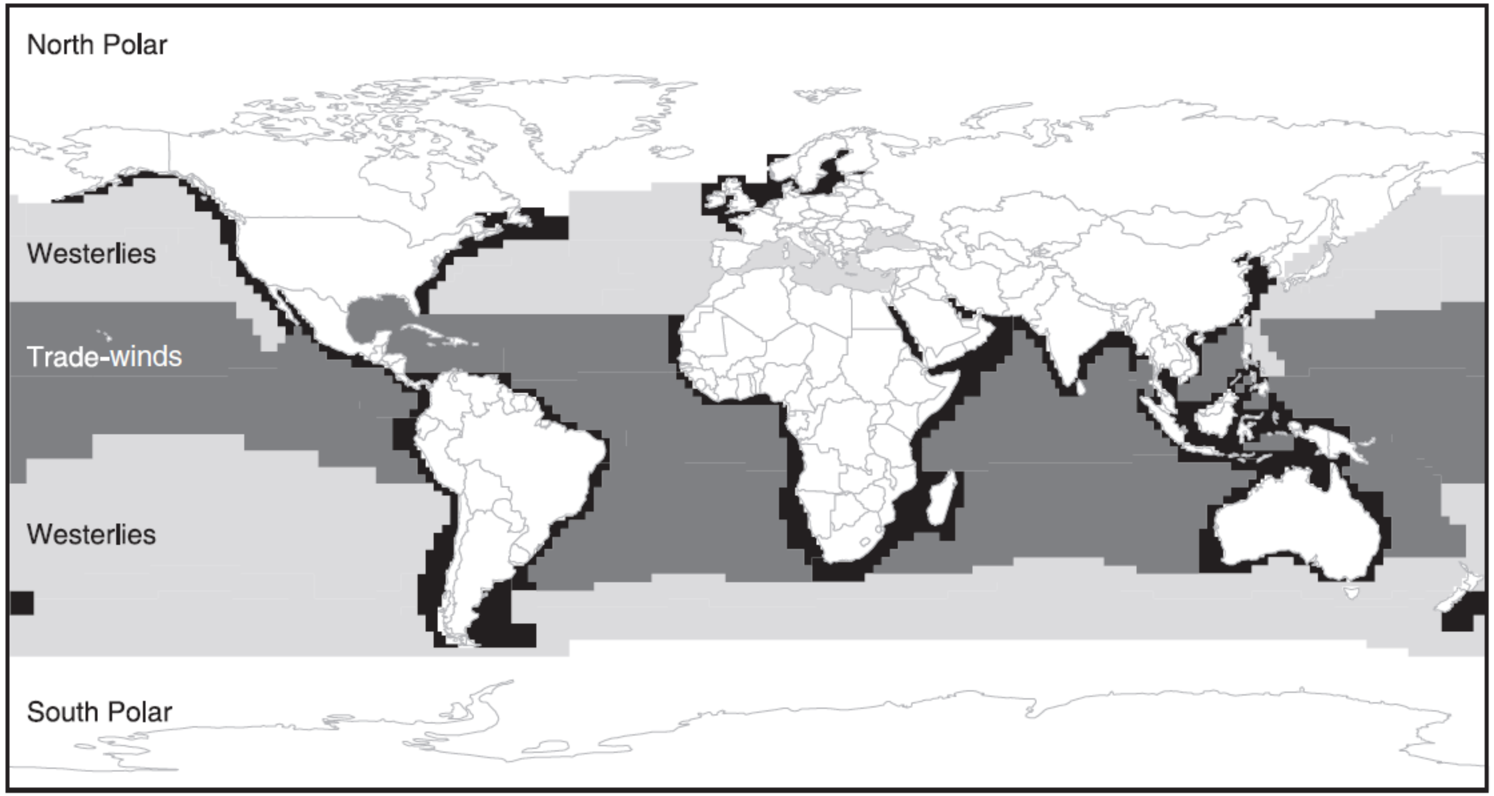


Figure 18.1. Classification of World's Oceans. Four "Biomes" were identified: Polar, Westerlies, Trade-winds, and Coastal Boundary (Longhurst et al. 1995; Longhurst 1998). The Coastal Boundary is indicated by a black border around each continent. Each of these Biomes is subdivided into Biogeochemical Provinces. The BGP of the Coastal Boundary Biome largely overlaps with LMEs identified by K. Sherman and coworkers (see Watson et al. 2003).

I. Fisheries of the world & status of stocks:
By biome : Tuna catches

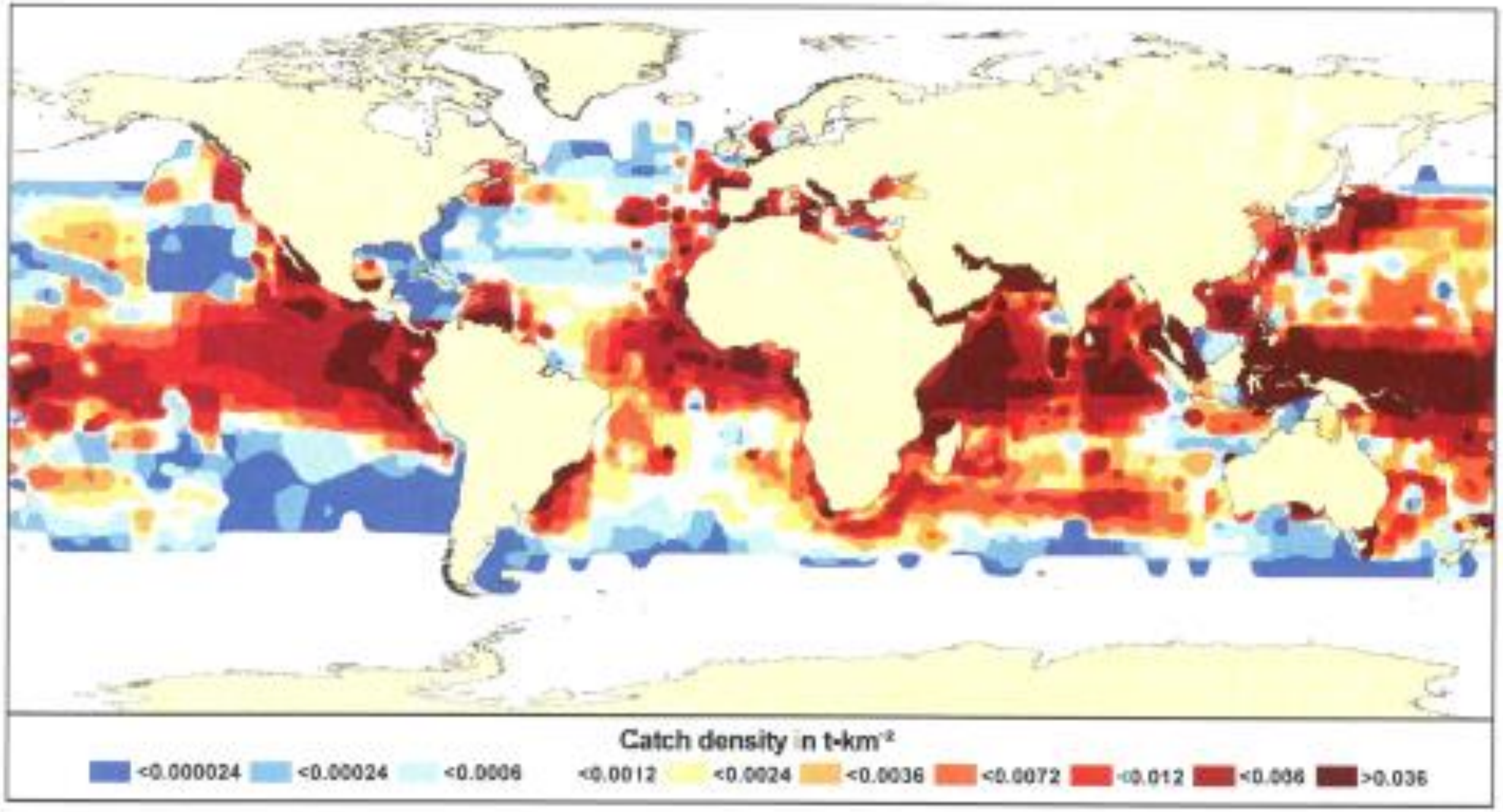
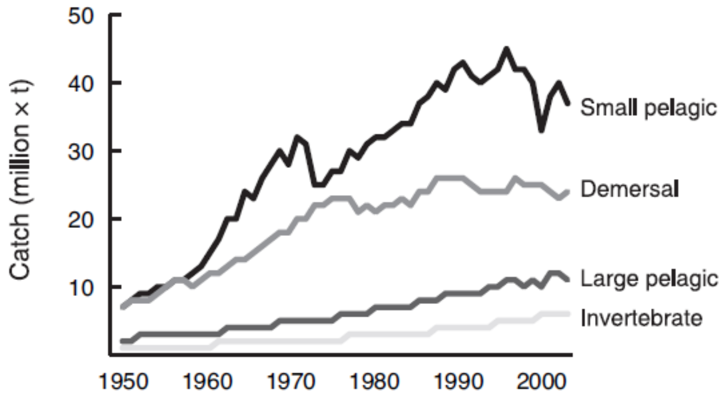


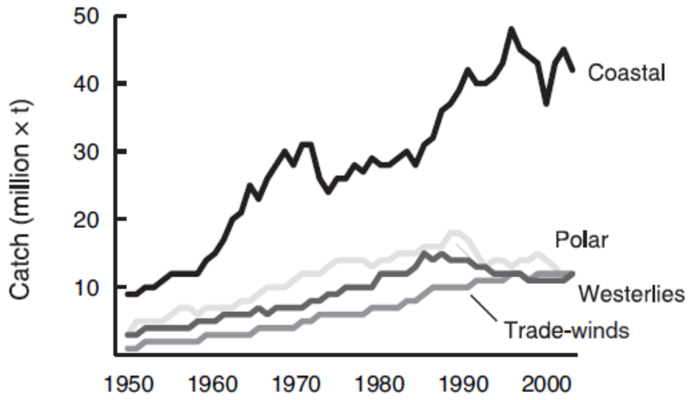
Figure 3.4. Average annual catches (t/km²) of large pelagic species (tuna and billfishes, as well as associated bycatch and discards) for 2000–2010 as derived for the present database and spatially assigned to the *Sea Around Us* 0.5° × 0.5° cells.

I. Fisheries of the world & status of stocks: Global trend by biome

A fishery is defined by the amount and kind of fish caught and their monetary value.

(Pauly, D., and Zeller, D. (2016). Global Atlas of Marine Fisheries. Washington: Island Press.)

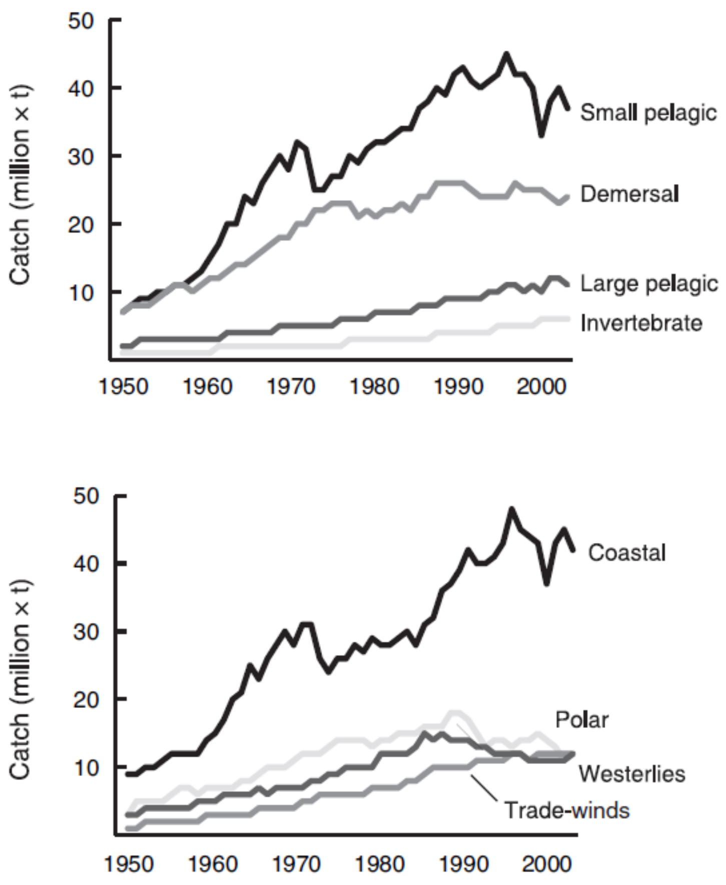




Pauly, D., and Alder, J. (2005). "Marine Fisheries Systems," in *Ecosystems and Human Well-being:Current State and Trends, Volume 1*, 478–511.

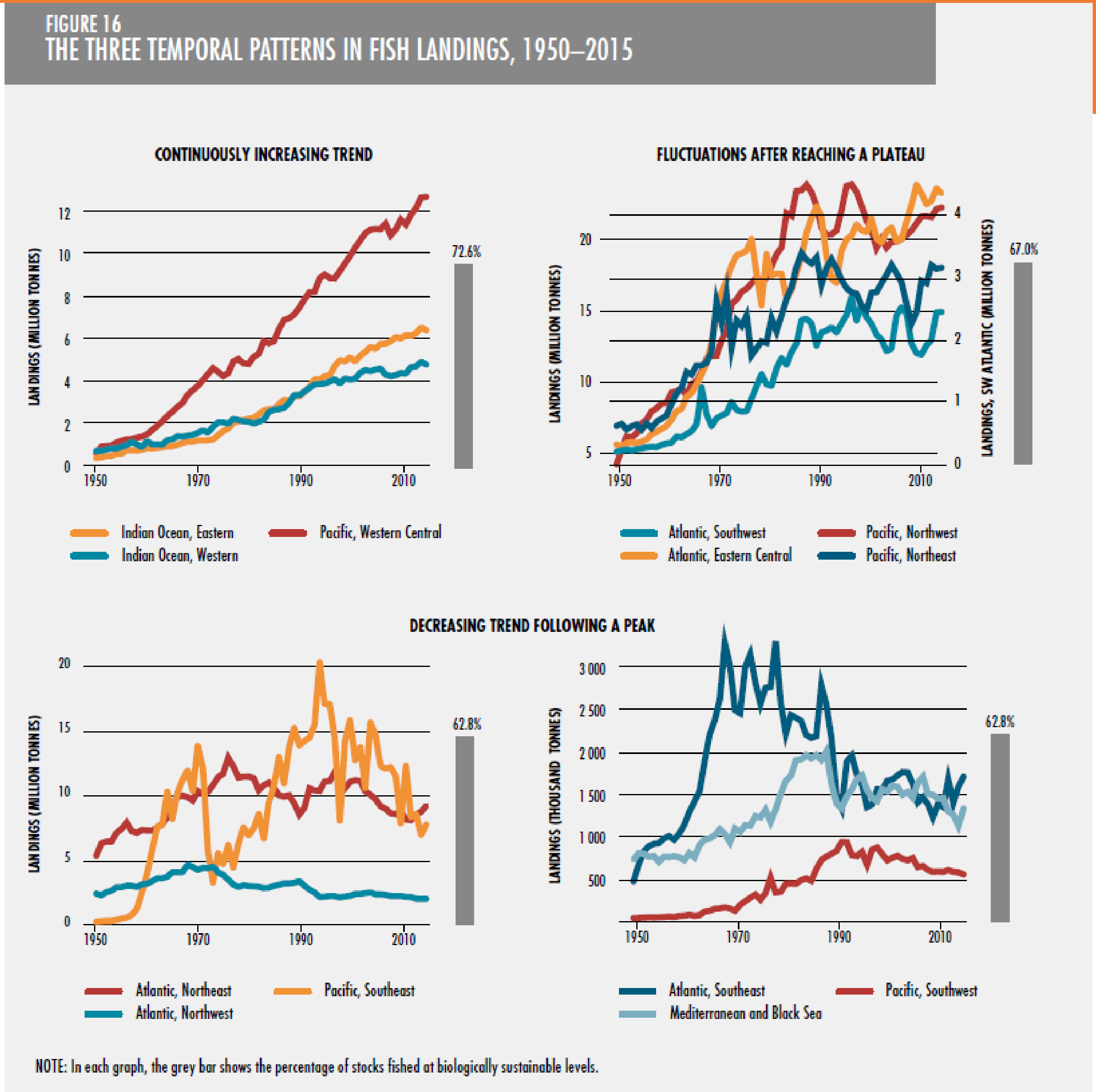
I. Fisheries of the world & status of stocks: Global trend by biome

- **Typical species**
- **Small pelagics : Sardine, Sardinella, Anchovies, Herring**
- **Demersal: Gadids (Hake), groupers, serranids, flatfish, eels**
- **Large pelagics: Tuna, billfish**
- **Invertebrate: Crustaceans, molluscs**



I. Fisheries of the world & status of stocks: Global trend by biome

FAO (2018). *The State of the World Fisheries and Aquaculture*. Rome



I. Fisheries of the world & status of stocks:
By fishing gear and target species = metier

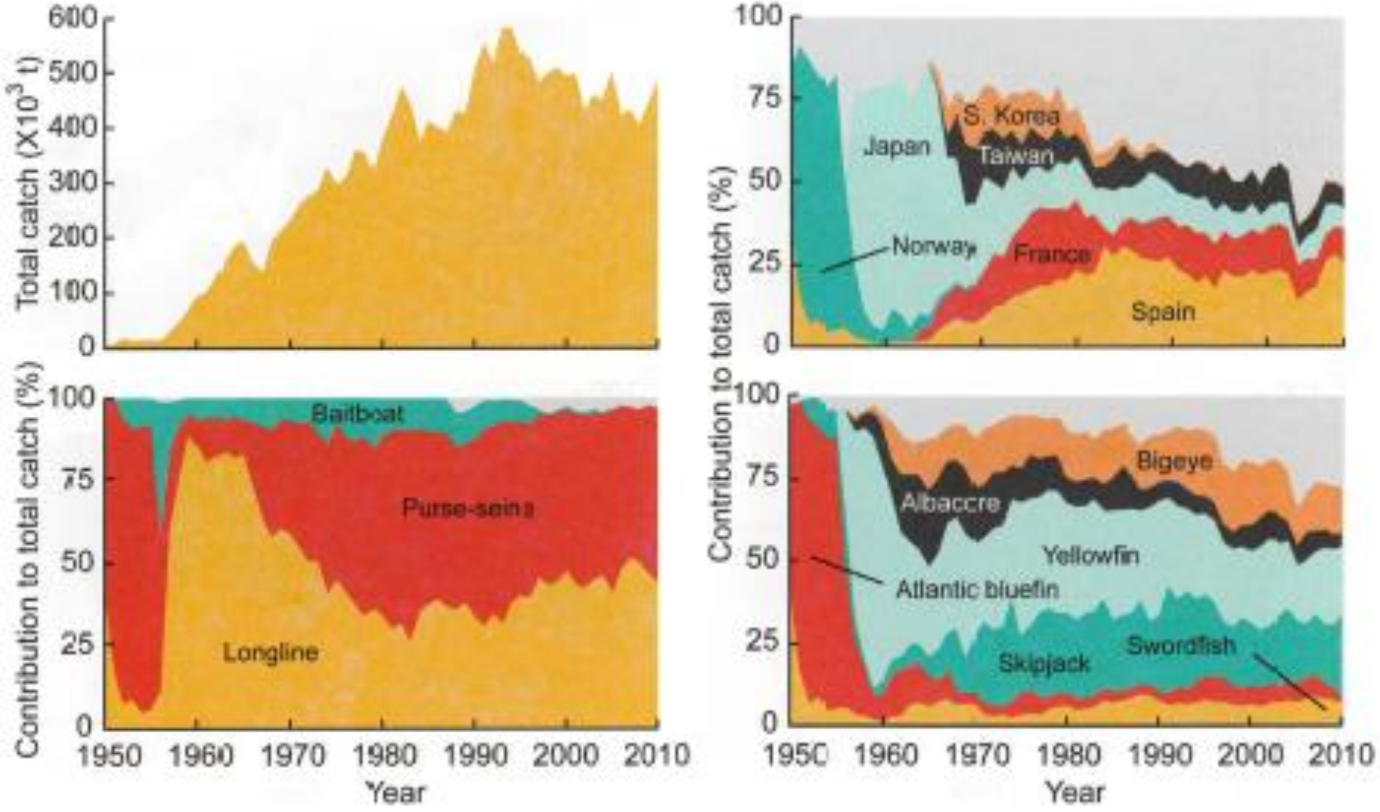


Figure 3.1. Industrial catch of large pelagic species in the Atlantic Ocean, 1950–2010. The top left panel shows nominal catches (without bycatch), whereas the top right, bottom left, and bottom right panels show this total catch as percentage contributions disaggregated by country, gear, and species, respectively. Gray areas are "other."

I. Fisheries of the world & status of stocks: By fishing gear and target species = metier

- **Purse seining**

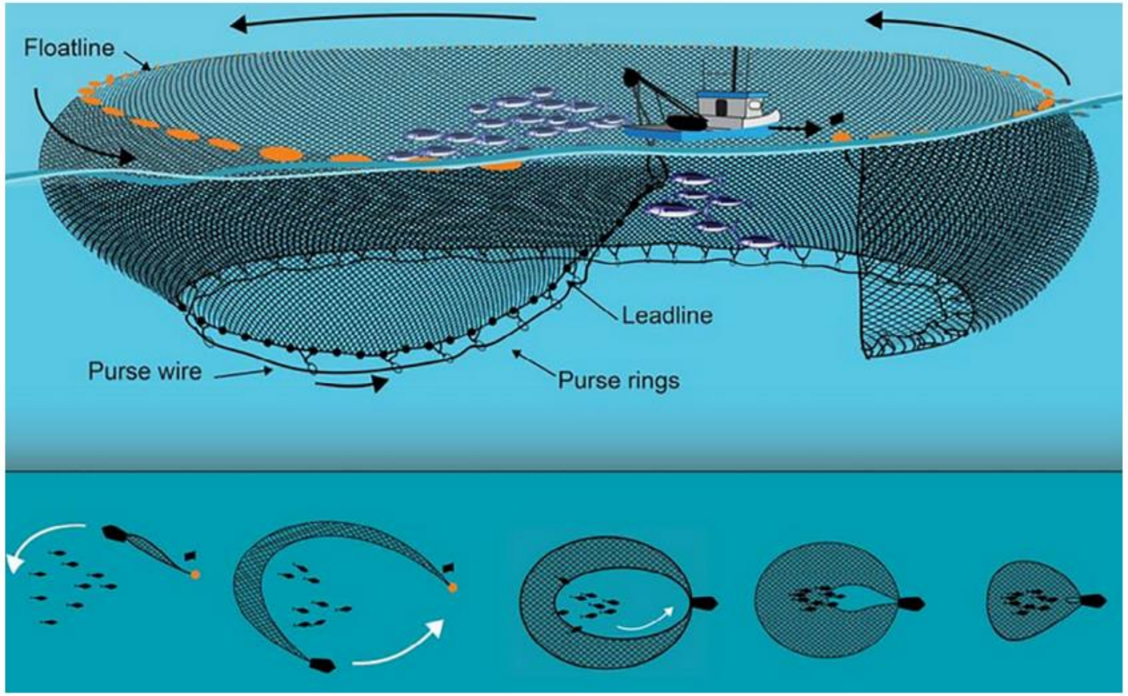


Fig. 6. The purse seine (Australian Fisheries Management Authority).

I. Fisheries of the world & status of stocks: By fishing gear and target species = metier

- **Long-lining**

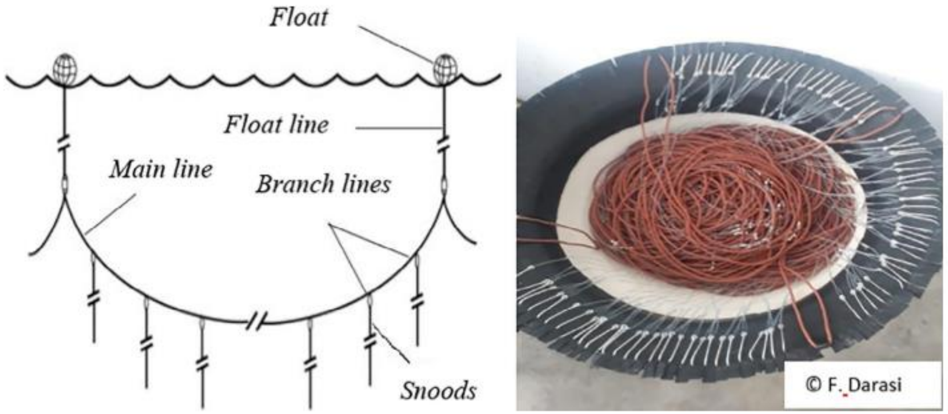


Fig. 3. Surface longline (Beverly et al., 2003).

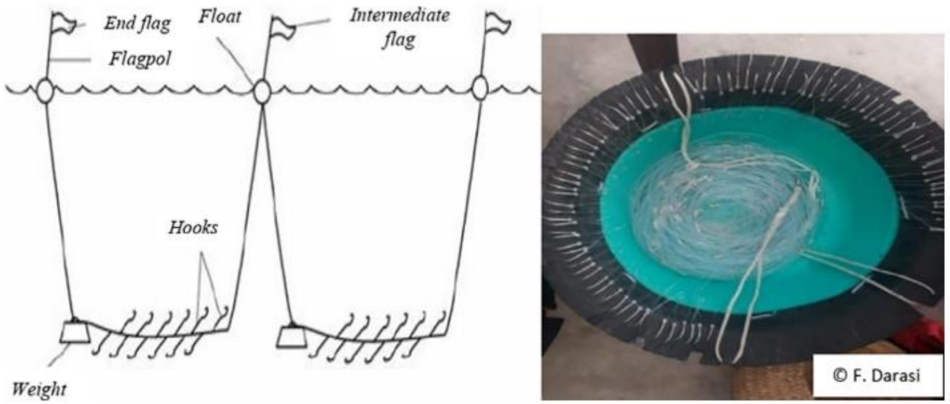


Fig. 4. Bottom longline (Echwikhi, 2011).

I. Fisheries of the world & status of stocks: By fishing gear and target species = metier

- **Trawling,**
- **demersal** and
- **pelagic**

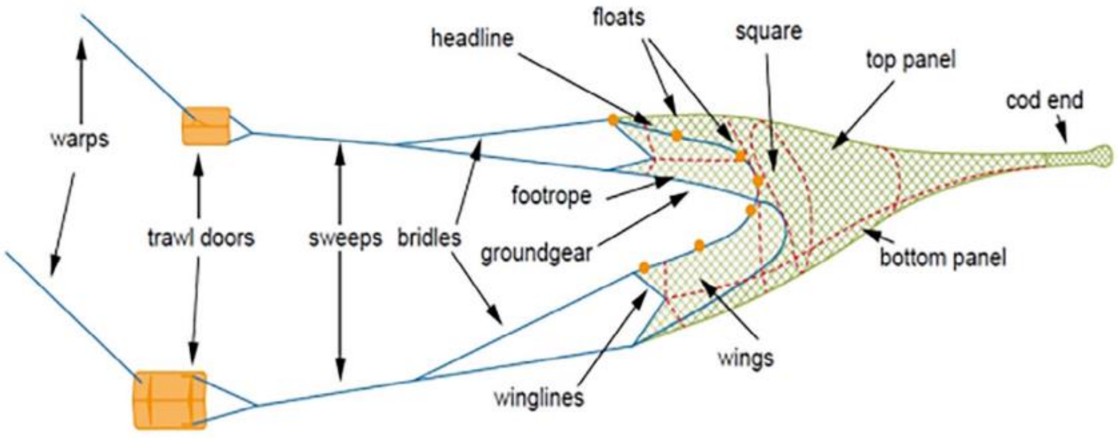


Fig. 5. Standard otter trawl design of bottom trawl (Weissenberger, 2015).

I. Fisheries of the world & status of stocks: By status of the stocks

- **A fishery is defined by the amount and kind of fish caught and their monetary value.**

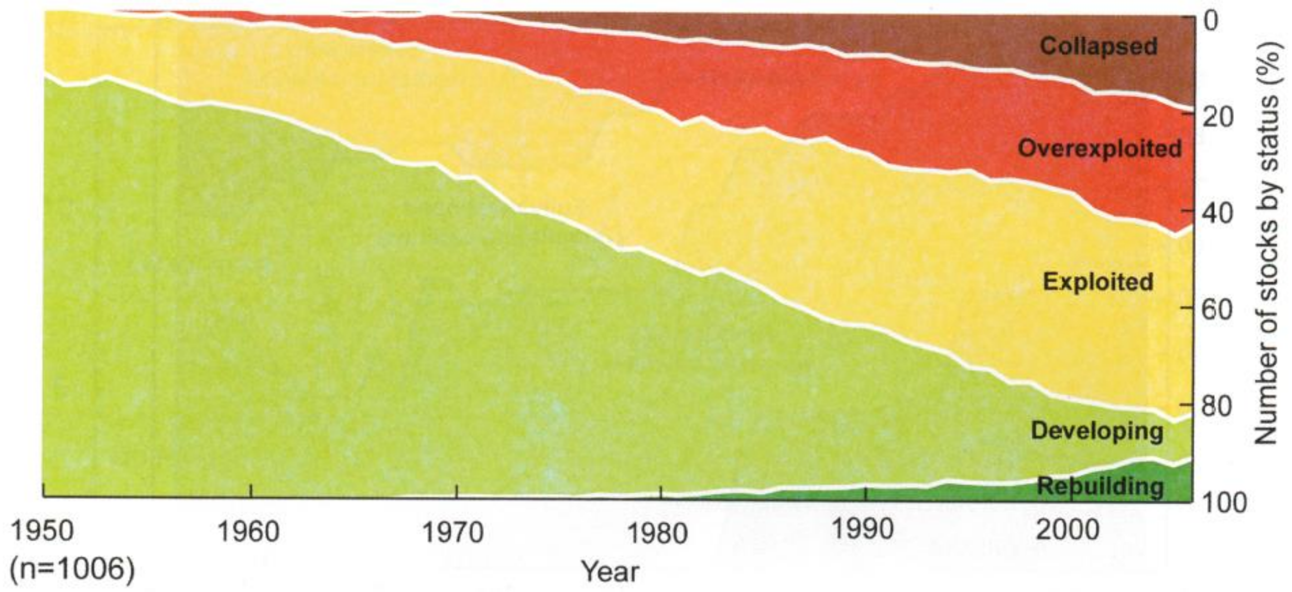


Figure 1.3. Stock-status plots (SSPs) based on more than 1,000 stocks worldwide, whose "developing" category combines the "undeveloped" and "developing" categories of figure 1.2 and which include a new category ("rebuilding"), which will hopefully increase with time (Kleisner et al. 2013). The 2048 projection mentioned in the text was derived by reading an SSP semihorizontally, that is, by extrapolation forward (and downward) from the line separating "overexploited" from "collapsed" stocks. Note the similarity of the trends suggested by this and figure 1.2, whose "senescent" or equivalent categories ("overexploited" and "collapsed") are clearly increasing. (Modified from Kleisner et al. 2013.)

I. Fisheries of the world & status of stocks: Status of the stock and catches – exploitation pattern

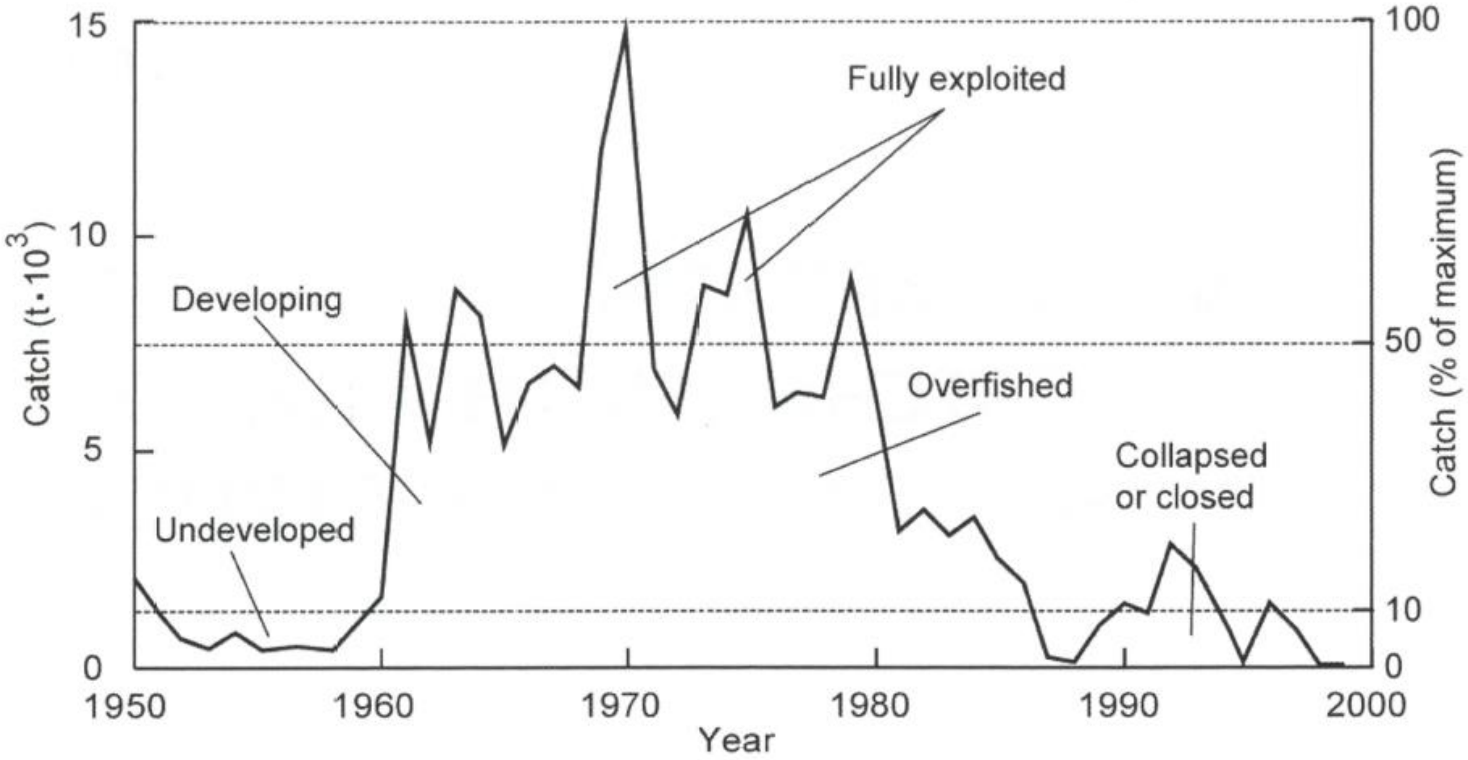


Figure 1.1. A typical catch time series, as can be used in conjunction with the method of Martell and Froese (2013) to perform a basic assessment of the fishery that generated that catch. The scale to the right defines the categories ("undeveloped," "developing," "fully exploited," etc.) used to describe the status of the underlying fisheries.

I. Fisheries of the world & status of stocks: Status of the stock and economic indicators

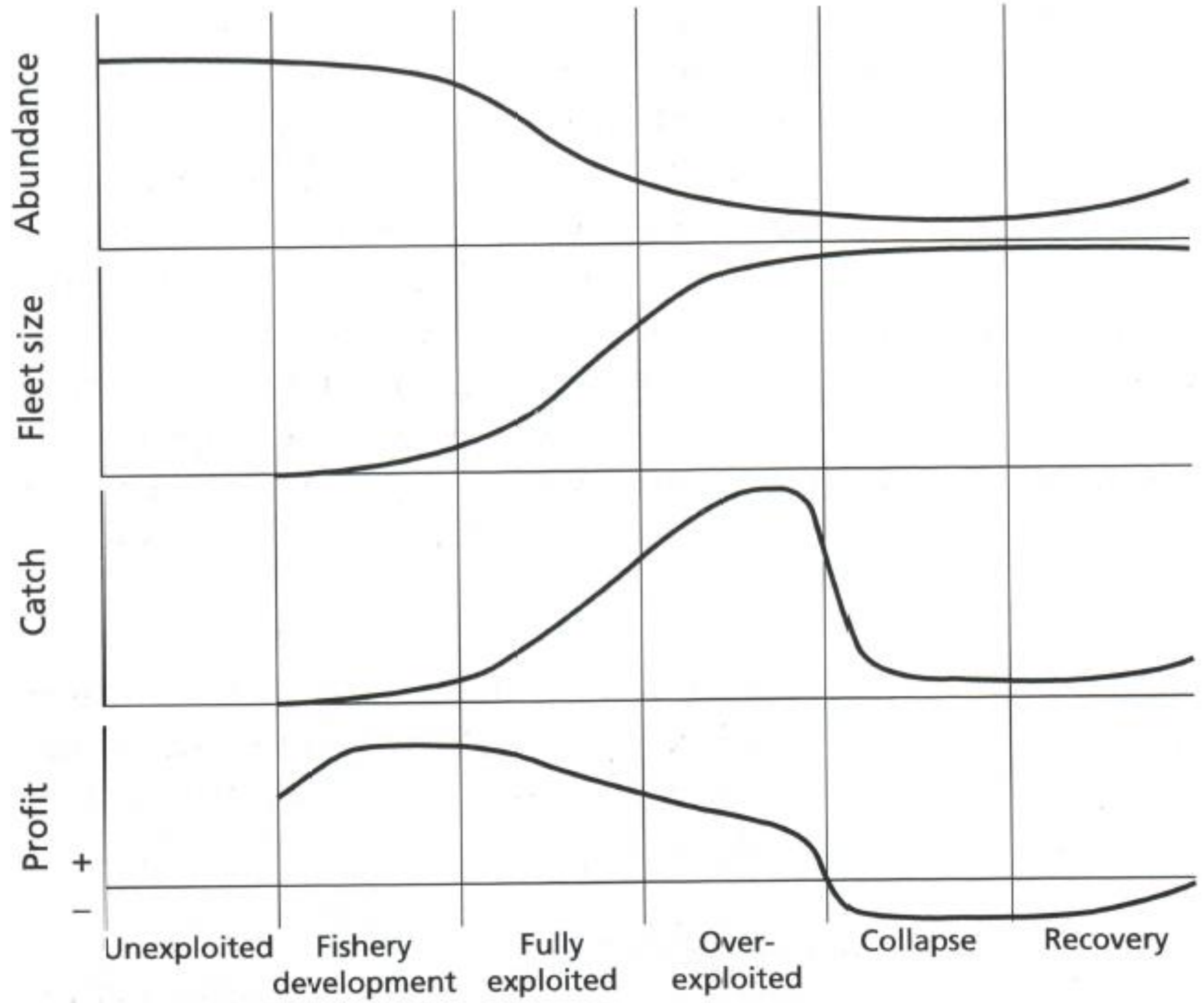
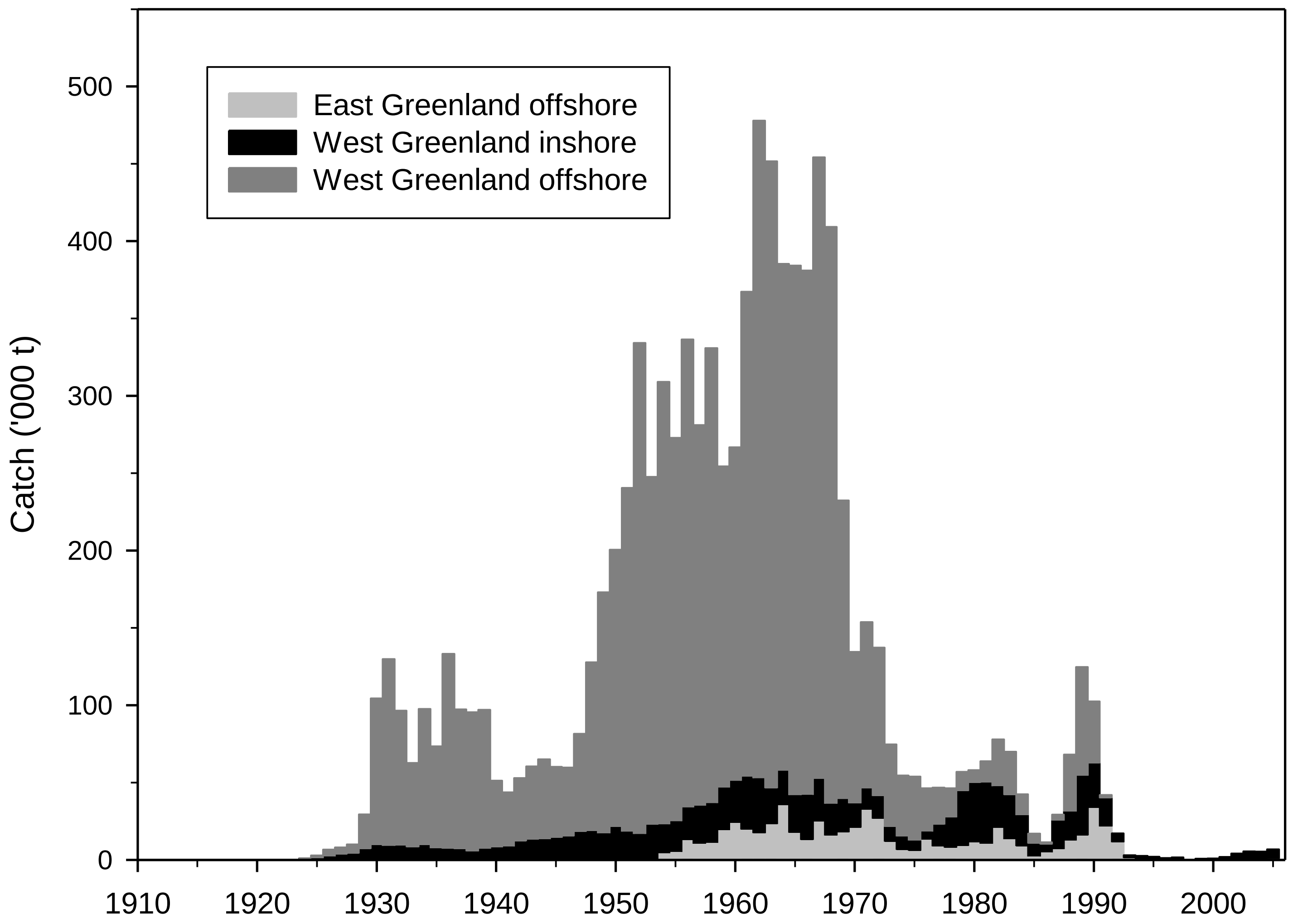


Fig. 1.8 Trends in the abundance of fished species, fleet size or fisher number, catch and profit as a fishery is developed and exploited through to collapse and recovery. Based on Hilborn and Walters (1992).

Greenland cod – exploitation pattern

- **Example of a fisheries from the initial stage to collapse and slow recovery – cod, *Gadus morhua* , off Greenland**



Seamount fisheries – exploitation pattern

- **Boom-and-bust fisheries: even faster collapse of a small stock with limited recruitment**

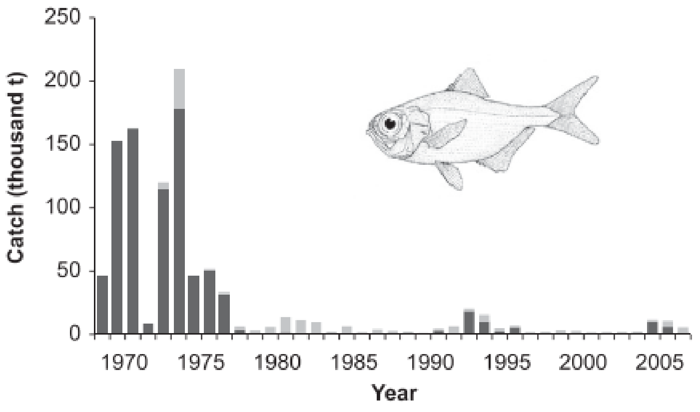
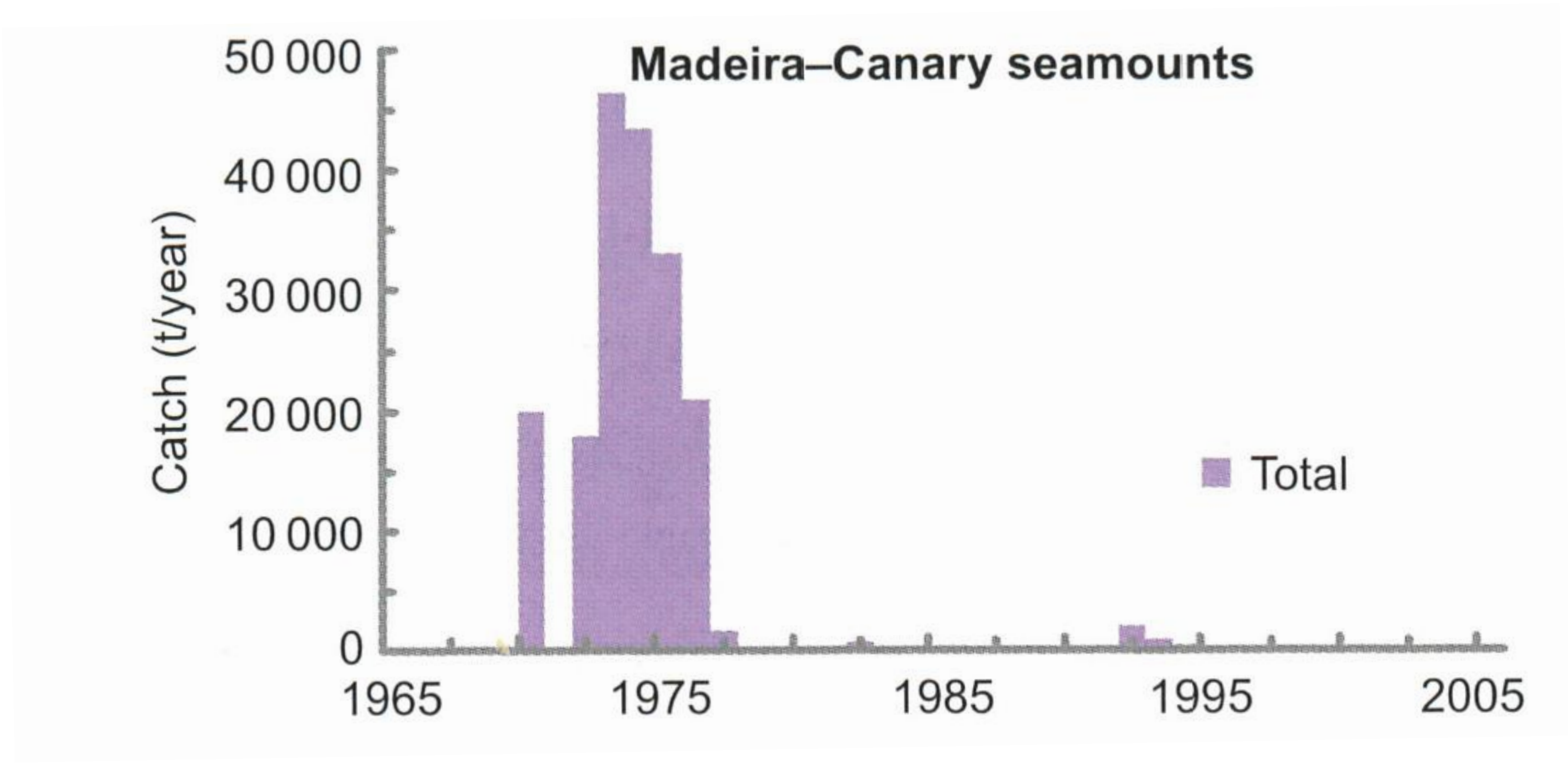


Fig. 4. Catches of slender armourhead (dark gray) and alfonsino (light gray) from Emperor and Hawaiian seamounts [80,133,148]. Splendid alfonsino image: wikepedia.org.



Norse EA, Brooke S, Cheung WWL, Clark MR, Ekeland I, Froese R, et al. Sustainability of deep-sea fisheries. Mar Policy. 2012;36: 307–320.

I. Fisheries of the world & status of stocks: By sector

- **A fishery is defined by the amount and kind of fish caught and their monetary value.**

- **(Pauly, D., and Zeller, D. (2016).**
- **Global Atlas of Marine Fisheries. Washington: Island Press.)**

- **Industrial sector**
- **Artisanal sector**
- **Subsistence sector**
- **Recreational sector**

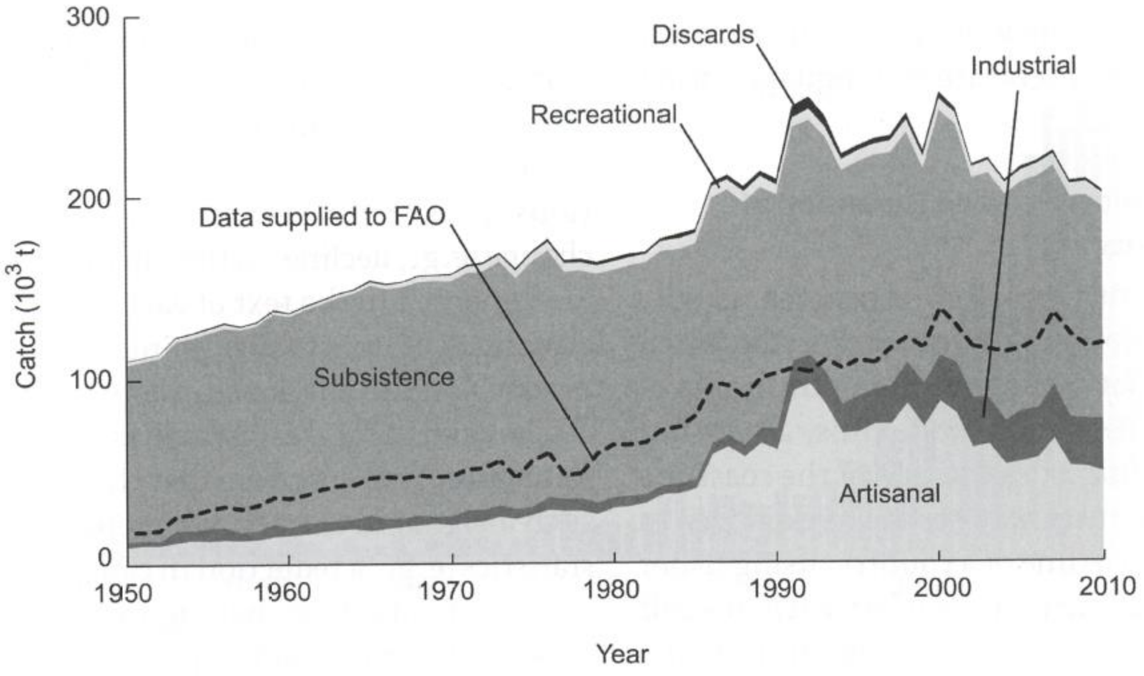


Figure 2.4. Catch reconstruction for the 25 Pacific island countries, states, and territories (Zeller et al. 2015) by the fishing sectors defined here: industrial (large-scale commercial), artisanal (small-scale commercial), subsistence (small-scale noncommercial), and recreational (small-scale noncommercial), with discards shown separately, and the official reported data as presented by FAO on behalf of these entities overlaid as a line graph. This clearly demonstrates the preponderance of commercial catch data in officially reported data as presented by FAO to the global community on behalf of countries. Note that industrial fisheries for large pelagic species (i.e., tuna and billfishes) are excluded from consideration by Zeller et al. (2015) unless they are conducted by truly domestic fleets. These industrial large pelagic fisheries and their catches are addressed separately using a global approach (see chapter 3). (Modified from Zeller et al. 2015.)

I. Fisheries of the world & status of stocks: By sector

TABLE 15
REPORTED NUMBER OF MOTORIZED AND NON-MOTORIZED VESSELS BY LOA CLASS IN FISHING FLEETS FROM SELECTED COUNTRIES AND TERRITORIES, 2016

Country	Non-motorized <12 m	Non-motorized 12–24 m	Non-motorized >24 m	Motorized <12 m	Motorized 12–24 m	Motorized >24 m
Africa						
Angola	5 337			3 785	114	156
Benin	51 771			1 363	134	14
Mauritius	130			1 556	36	9
Senegal	3 987	414	2	9 646	4 958	161
Sudan				1 375	21	2
Tunisia	8 360			3 862	656	266

Artisanal fleet , Mbour Senegal, 2015

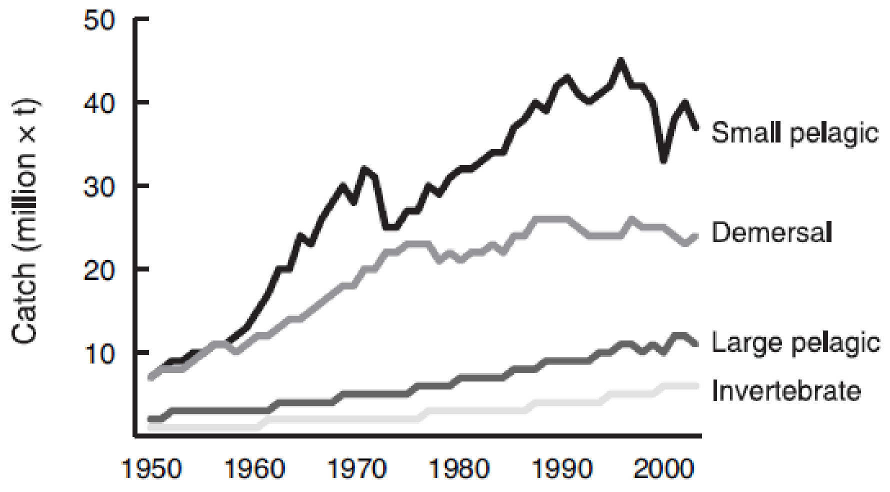
Beach seining , Mindelo, 2018

I. Fisheries of the world & status of stocks: Mesopelagics biomass – the unfished target

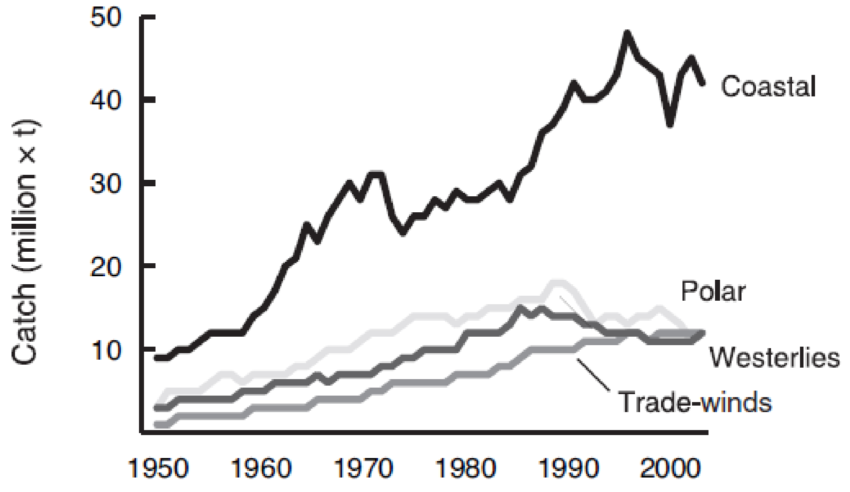
Table 3 | Fishes biomass Ecotroph estimates.

Trophic efficiency between TL	% PP to food chain		
	70%	**80%**	**90%**
5%	2,322	2,655	2,985
10%	10,691	12,224	13,744
20%	57,054	64,148	71,299

Ecotroph fishes biomass estimates (millions of tons) between 40° N and 40° S as a function of the efficiency between trophic levels and the flux from PP to the first trophic level (TL).



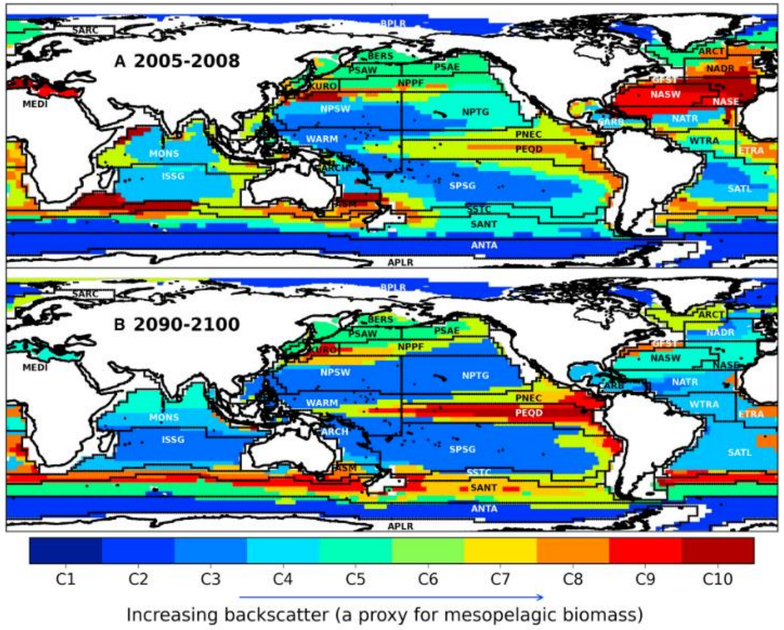
Mesopelagics **15000 millions of tons** (above)
vs.
400 millions of tons* demersal, large and small pelagics,invertebrates (right)



Pauly, D., and Alder, J. (2005). “Marine Fisheries Systems,” in *Ecosystems and Human Well-being:Current State and Trends, Volume 1*, 478–511.
Irigoien X, Klevjer TA, Røstad A, Martinez U, Boyra G, Acuña JL, et al. Large mesopelagic fishes biomass and trophic efficiency in the open ocean. Nat Commun. 2014;5: 3271. doi:10.1038/ncomms4271

* Harvest rate of 20 %

I. Fisheries of the world & status of stocks: Mesopelagics biomass – the unfished target



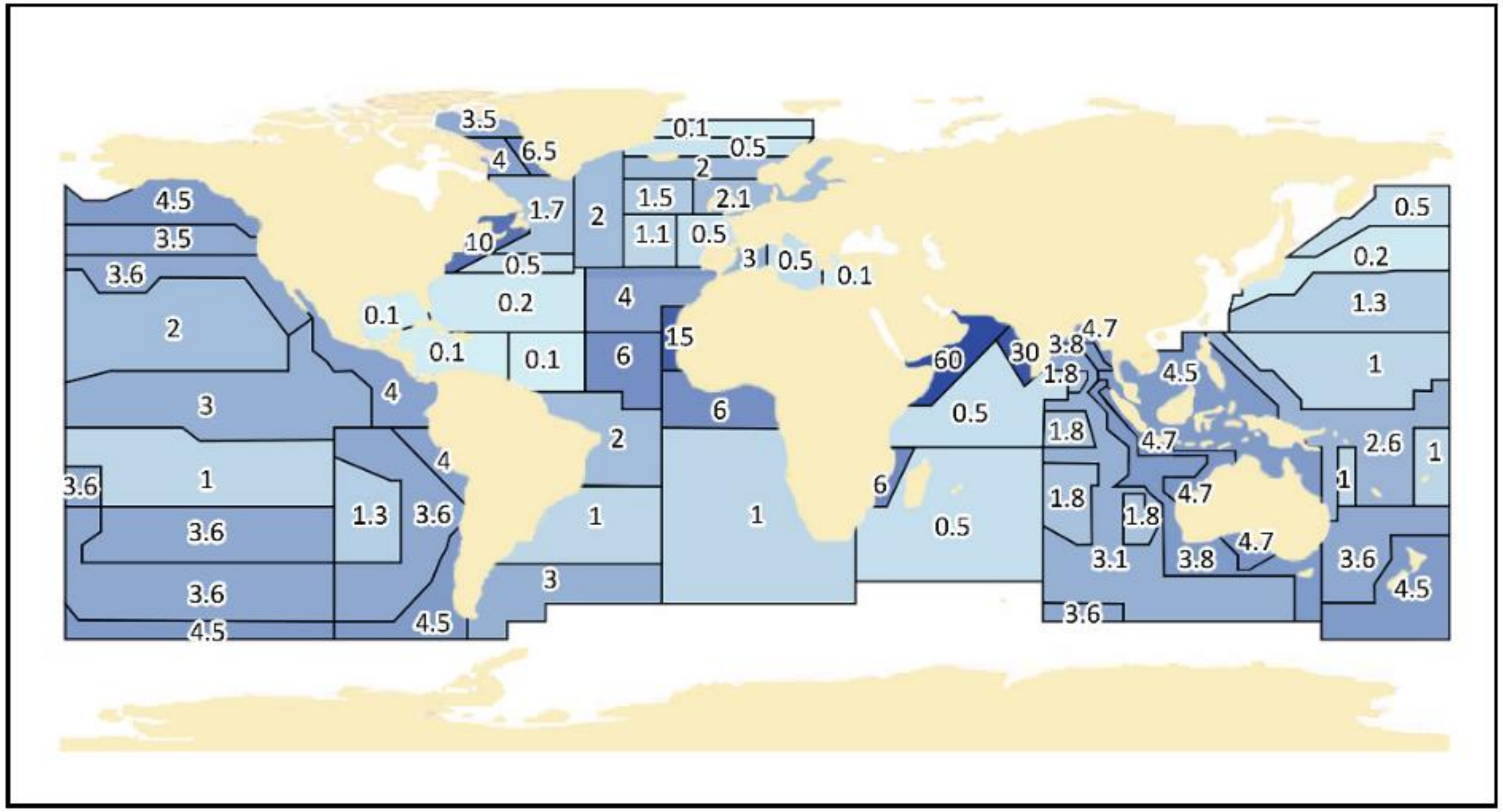
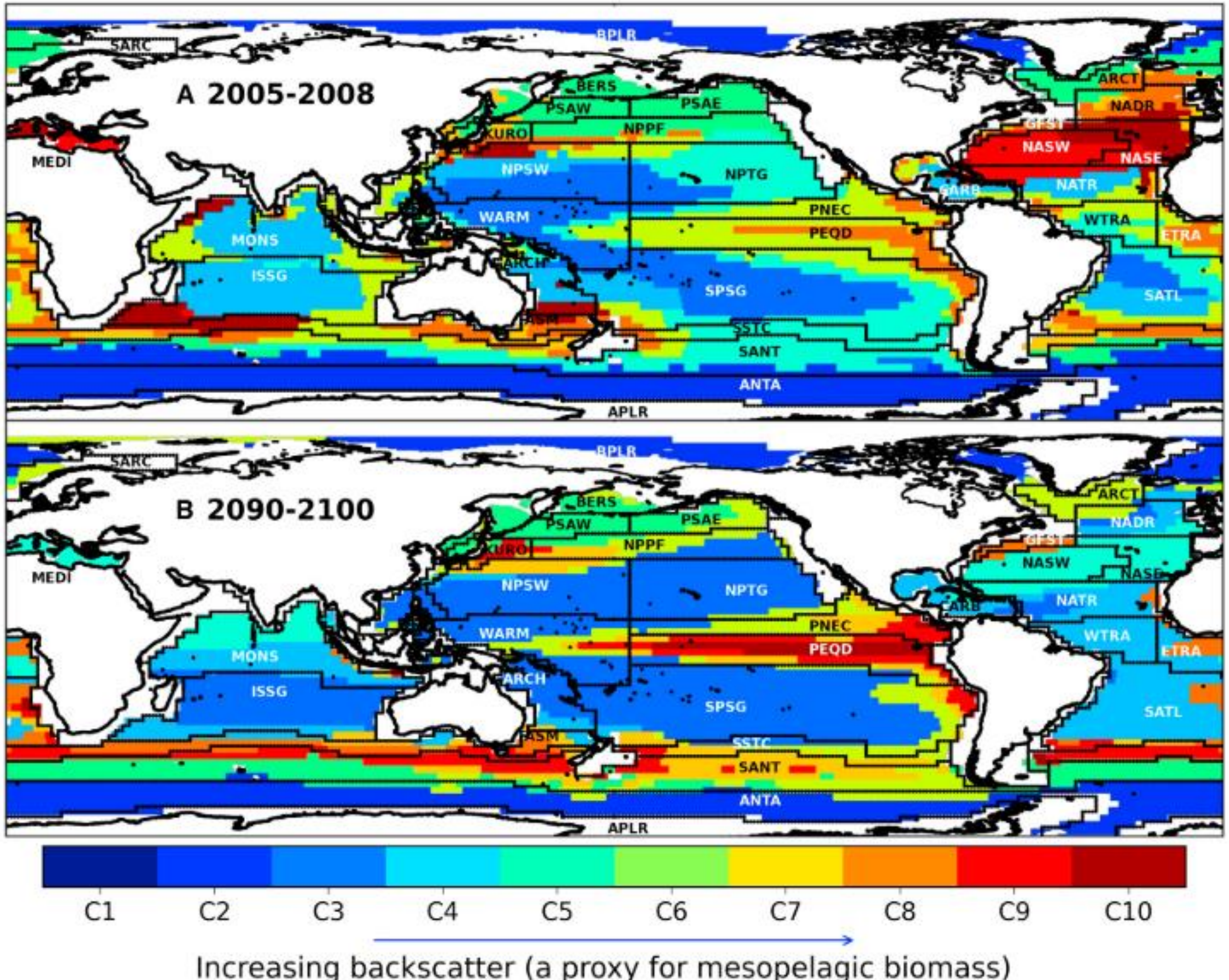
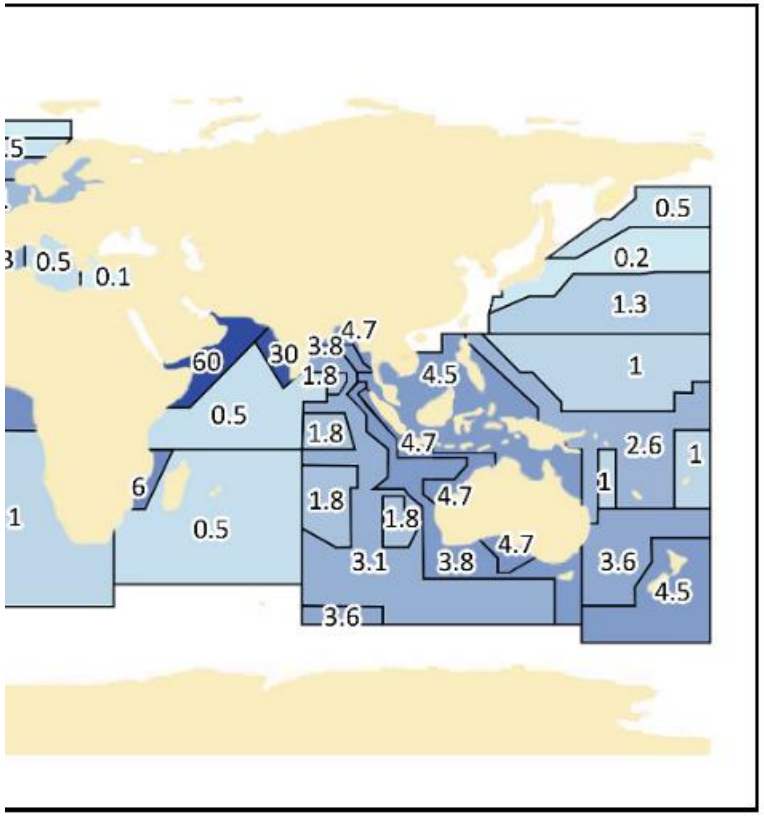


Figure 2. Biomass of mesopelagics (in $g \cdot m^{-3}$) based on data in Gjøsaeter and Kawaguchi [2], with mean estimates per stratum corrected using ESRI's ArcGIS 9.0. Light blue refers to low densities of mesopelagics (with means in $g \cdot m^{-3}$), dark blue to high densities, white refers to unsampled sea areas, and yellow to land.

Pauly D, Piroddi C, Hood L, Bailly N, Chu E, Lam V, et al. The biology of mesopelagic fishes and their catches (1950– 2018) by commercial and experimental fisheries. J Mar Sci Eng. 2021;9. doi:10.3390/jmse9101057
Proud R, Cox MJ, Andrew S. Brierley. Biogeography of the Global Ocean's Mesopelagic Zone. Curr Biol. 2017;27: 113–119.

I. Fisheries of the world & status of stocks: Mesopelagics biomass – the unfished target





based on data in Gjøsaeter and Kawaguchi [2], with ESRI's ArcGIS 9.0. Light blue refers to low densities blue to high densities, white refers to unsampled sea

Mesopelagic commercial fisheries

Lampanyctodes hectoris, lanternfish, 5-6 cm

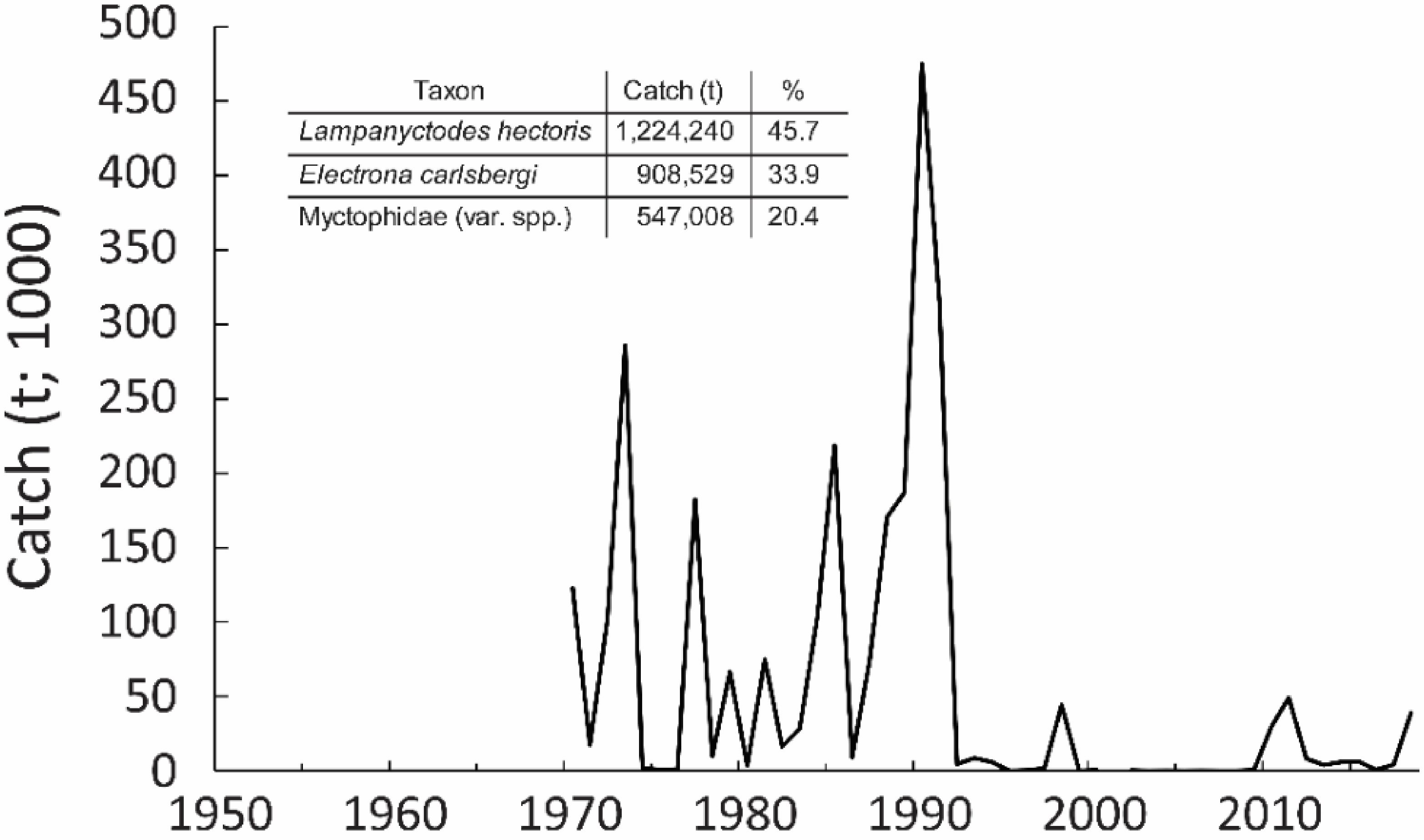


Figure 3. Landings officially reported to the FAO by its member countries totaling 2.68 million tonnes from 1950–2018, mainly the U.K. (South Georgia and Sandwich Islands, reporting 47%), South Africa (Atlantic and Cape, 37%), and Iceland (13%).

1. Pauly D et al. J Mar Sci Eng. 2021;9. doi:10.3390/jmse9101057
2. Remesan MP et al.. Fish Technol. 2019;56: 243–253.

Mesopelagic commercial fisheries

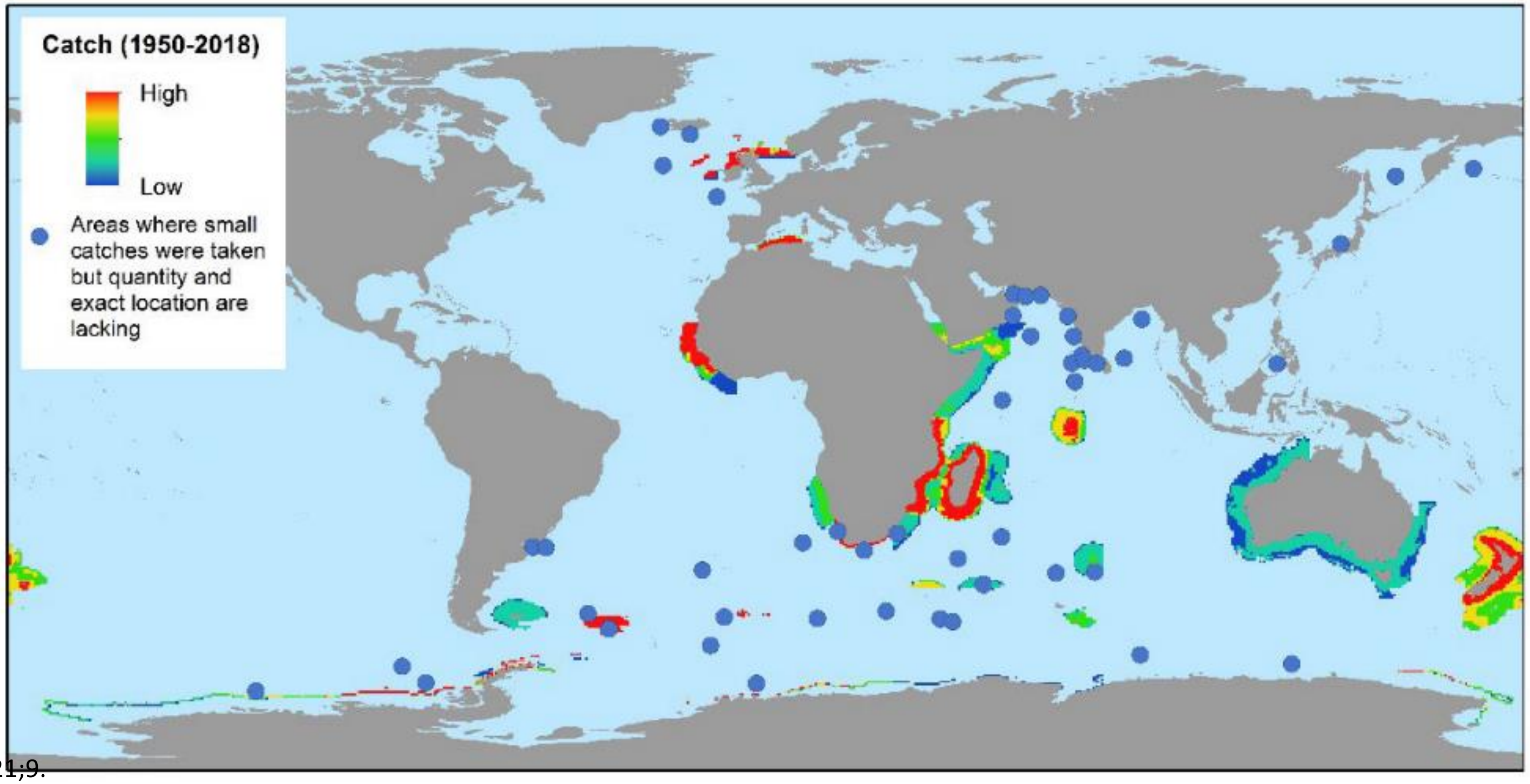


Figure 4. *Sea Around Us* reconstructed catches of mesopelagic fishes for the period 1950–2018 in the global oceans. Areas where small catches are taken (blue dots) but where quantity and exact location are unknown are listed in the Supplementary Materials and/or mentioned in the text.

1. Pauly D et al. J Mar Sci Eng. 2021;9. doi:10.3390/jmse9101057
2. Remesan MP et al.. Fish Technol. 2019;56: 243–253.

Mesopelagic commercial potential

Open ocean catches comprise more than only fish:

No clean catch - a mix of fish (70 %), pelagic shrimp (15%) and jellyfish (15%)

Shelf catches can contain more fish (~95%) → pseudo- oceanic species in the neritic/coastal and shelf zone

No use for human consumption → wax ester

Berntssen MHG, et al. . Foods. 2021;10: 1–19. doi:10.3390/foods10061265

Mesopelagic commercial potential

Contaminants

Berntssen MHG, et al. . Foods. 2021;10: 1–19. doi:10.3390/foods10061265

Table 3. Concentrations of dioxins (PCDD/F), dioxin-like PCBs (DL-PCBs) (WHO-TEQ pg g-1 per DW), polybrominated diphenyl ether mixtures (PBDEs) and organochlorine pesticides (ng g^{-1} per DW) (mean, minimum–maximum, n = 4) in the raw mesopelagic biomass, the concentration in processed mesopelagic oil, commercial pelagic fish oils (n = 9). Concentrations are expressed as upper-bound (UB) with undetected congeners expressed as limit of quantification or lower-bound (LB) with undetected congeners expressed as zero. For comparison, the maximum residue level (ML) based on upper-bound concentrations, given in EU Directive 2002/32/EC, are shown.

Compounds	Processing	Surveillance of Commercial Samples	Comparison to Legislation	
	Mesopelagic Oil	Pelagic Fish Oil	Fish Oil	Animal Feed
	Mean (min–max)	Mean (min–max)	ML	ML
Sum (PCDD+PCDF) (UB)	1.4 (1.1–1.6)	1.6 (0.9–3.2)	5.00	1.75
Sum (PCDD+PCDF) (LB)	0.50 (0.28–0.71)			
DL-PCBs (UB)	0.74 (0.39–0.90)	2.4 (0.4–5.1)		
DL-PCBs (LB)	0.73 (0.38–0.89)			
Sum PCDD/F Dl-PCBs (UB)	2.1 (1.5–2.4)	4.0 (1.0–8.0)	20	6
Sum PCDD/F Dl-PCBs (LB)	1.2 (0.66–1.6)			
PCB-6 UB	8.9 (6.1–12)	37 (3.0–79)	175	40
PCB-6 LB	8.9 (6.1–12)			

Mesopelagic commercial potential

Contaminants

Using a feed-to-fillet aquaculture transfer model, the use of mesopelagic processed aquafeed ingredients was estimated to reduce the level of dioxins and PCBs by ~30% in farmed seafood such as Atlantic salmon.

Berntssen MHG, et al. . Foods. 2021;10: 1–19. doi:10.3390/foods10061265

Table 3. Concentrations of dioxins (PCDD/F), dioxin-like PCBs (DL-PCBs) (WHO-TEQ pg g-1 per DW), polybrominated diphenyl ether mixtures (PBDEs) and organochlorine pesticides (ng g^{-1} per DW) (mean, minimum–maximum, n = 4) in the raw mesopelagic biomass, the concentration in processed mesopelagic oil, commercial pelagic fish oils (n = 9). Concentrations are expressed as upper-bound (UB) with undetected congeners expressed as limit of quantification or lower-bound (LB) with undetected congeners expressed as zero. For comparison, the maximum residue level (ML) based on upper-bound concentrations, given in EU Directive 2002/32/EC, are shown.

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PCB-6 LB	8.9 (6.1–12)			

Mesopelagic commercial potential

Based on estimated catch rates of 5 – 25 t/h or 1000 t per 5-day trip

„… We can reject the third hypothesis that expected increased costs (compared to likely prices/earnings), and thus the expected larger BEP of mesopelagic fishery, are too extensive to obtain an adequate profitability to conduct potential mesopelagic fishery with either current fleet or investment into new fleet capacity given different scenarios of economic BEP (covering among other prices, catch amounts, and costs per unit of effort). The current results indicate relatively high profit in most of the current pelagic fisheries as well as similar level of profits in potential mesopelagic fishery.“

Paoletti S et al. Front Mar Sci. 2021;08: 1–21. doi:10.3389/fmars.2021.720897

Mesopelagic commercial potential

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„… We can reject the third hypothesis that expected increased costs (compared to likely prices/earnings), and thus the expected larger BEP of mesopelagic fishery, are too extensive to obtain an adequate profitability to conduct potential mesopelagic fishery with either current fleet or investment into new fleet capacity given different scenarios of economic BEP (covering among other prices, catch amounts, and costs per unit of effort). The current results indicate relatively high profit in most of the current pelagic fisheries as well as similar level of profits in potential mesopelagic fishery.“

Paoletti S et al. Front Mar Sci. 2021;08: 1–21. doi:10.3389/fmars.2021.720897

"…Since fine-meshed trawl gears will be used, potential bycatch includes vulnerable species as well as other juvenile fish that might have commercial importance."

Consequences.

The ''tragedy of the commons'' has been recognized→ In 2006, United Nations General Assembly (UNGA) adopted a resolution on ''Sustainable Fisheries'' calling on states to undertake an

- explicit set of time-limited actions to ensure sustainability of deep-sea fisheries on the high seas and
- to protect vulnerable deep-sea ecosystems, consistent with the precautionary and ecosystem approaches.

Mesopelagic commercial potential → MEESO

Based on estimated catch rates of 5 – 25 t/h or 1000 t per 5-day trip

„… We can reject the third hypothesis that expected increased costs (compared to likely prices/earnings), and thus the expected larger BEP of mesopelagic fishery, are too extensive to obtain an adequate profitability to conduct potential mesopelagic fishery with either current fleet or investment into new fleet capacity given different scenarios of economic BEP (covering among other prices, catch amounts, and costs per unit of effort). The current results indicate relatively high profit in most of the current pelagic fisheries as well as similar level of profits in potential mesopelagic fishery.“

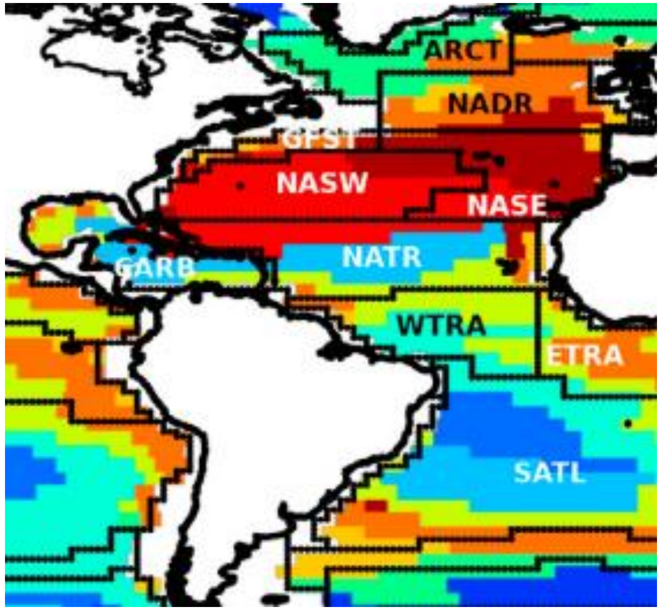
MEESO : Paoletti S et al. Front Mar Sci. 2021;08: 1–21. doi:10.3389/fmars.2021.720897

Consequences.
UNGA also requested that FAO develop ‘‘Guidelines for the management of deep-seas fisheries on the high seas.’’

- Keep catch rates low until knowledge, management capacity and measures for monitoring, control and surveillance increase
- RFMOs shall not to authorize deep-sea fisheries unless an impact assessment had been performed and measures adopted to prevent significant impacts on deep-sea ecosystems
- Where scientific information is uncertain, unreliable or inadequate, to ‘‘adopt precautionary management measures to ensure that fishing effort, capacity and catch levels did not exceed levels consistent with the sustainability of the fish stocks and non-target species.“

Norse EA, et al.. Mar Policy. 2012;36: 30–3207.

Biogeography of the Sea and oceanic features



Longhurst A. Ecological Geography of the Sea. San Diego: Academic Press; 1998.

Subpolar gyre

North Atlantic Sutropical Gyre

South Atlantic Subtropical Gyre

Subtropical Convergence

Coastal Upwelling: Benguela, Canary Current

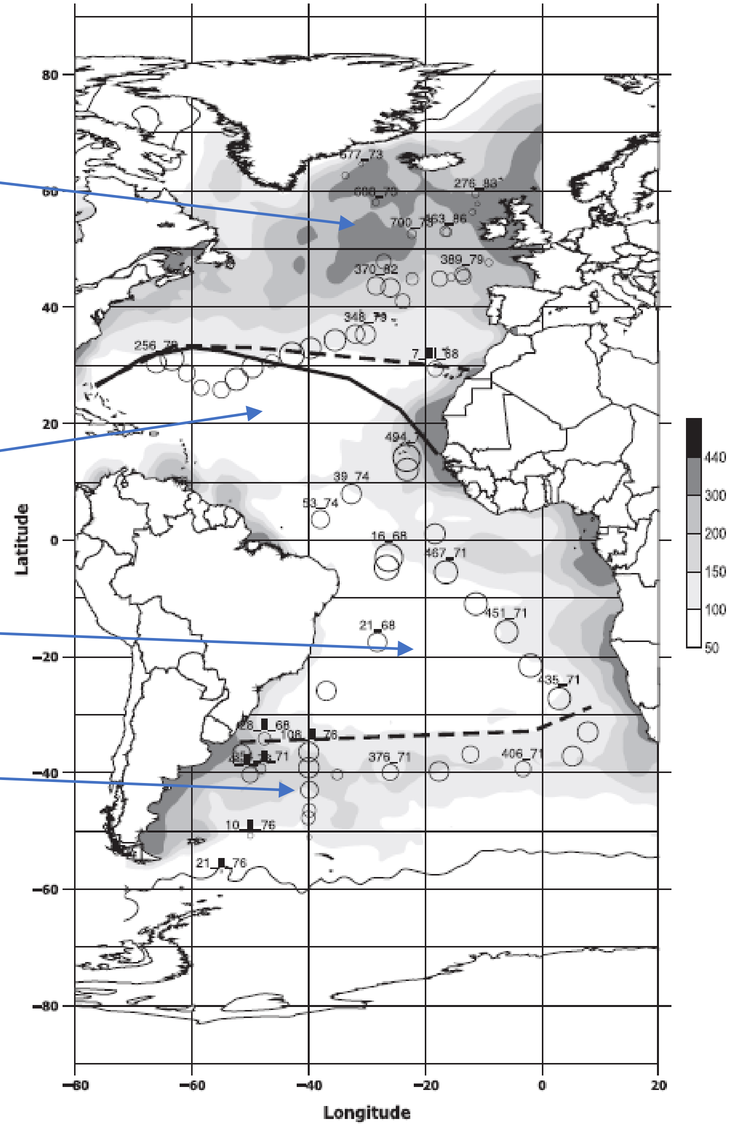
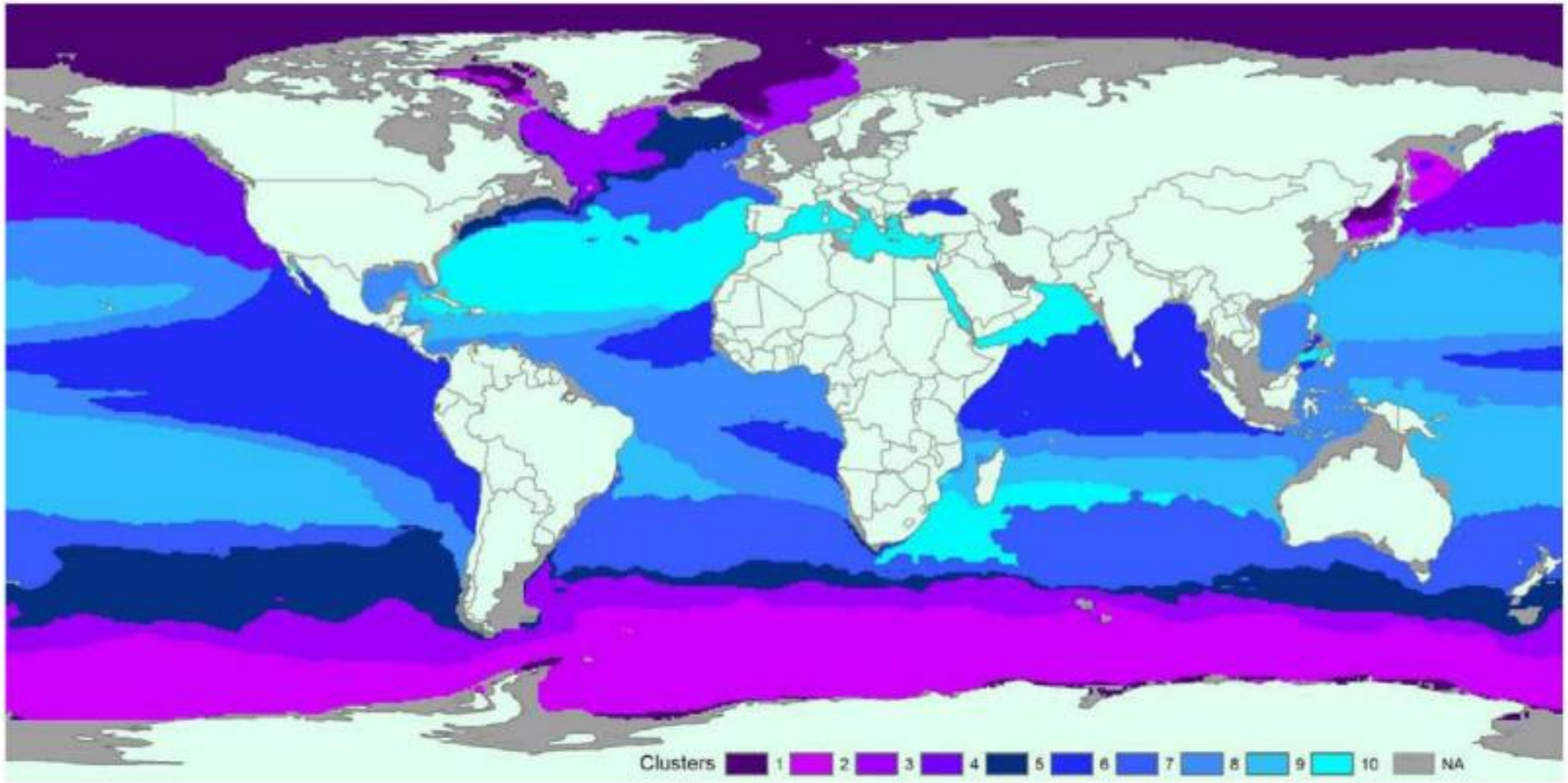


Figure 1 Sampling locations, local diversity (SL), distribution of primary production and biogeographical boundaries. Station bubbles indicate local species richness (SL). Bold full line: recent border between tropical and boreal faunas (Briggs, 1970); bold broken lines, border of mesopelagic subtropical seas (North: southern Sargasso Sea and southern African Sea, South: South Atlantic Subtropical Sea/transitional zone) (Backus *et al.*, 1977; Herman, 1979). Scale bar indicates annual primary production (gC m^{-2} year^{-1}).

Biogeography of the Sea and oceanic features

SST clustering

Fig. 1. Plot of 10 clusters values derived from the ISODATA analysis of global 0.5° resolution temperature, salinity and dissolved oxygen layers from the CARS (2009) model.



Sutton TT, et al. Deep Res Part I Oceanogr Res Pap. 2017;126: 85–102

Provinces in the Sea

- **Water mass distribution**
- **Oxygen minimum zones**
- **Temperature extremes**
- **Surface water productivity**
- **Biotic partitioning**

- 2 major EBUS
- The Guinea basin
- The subtropical gyres
- The subtropical convergence

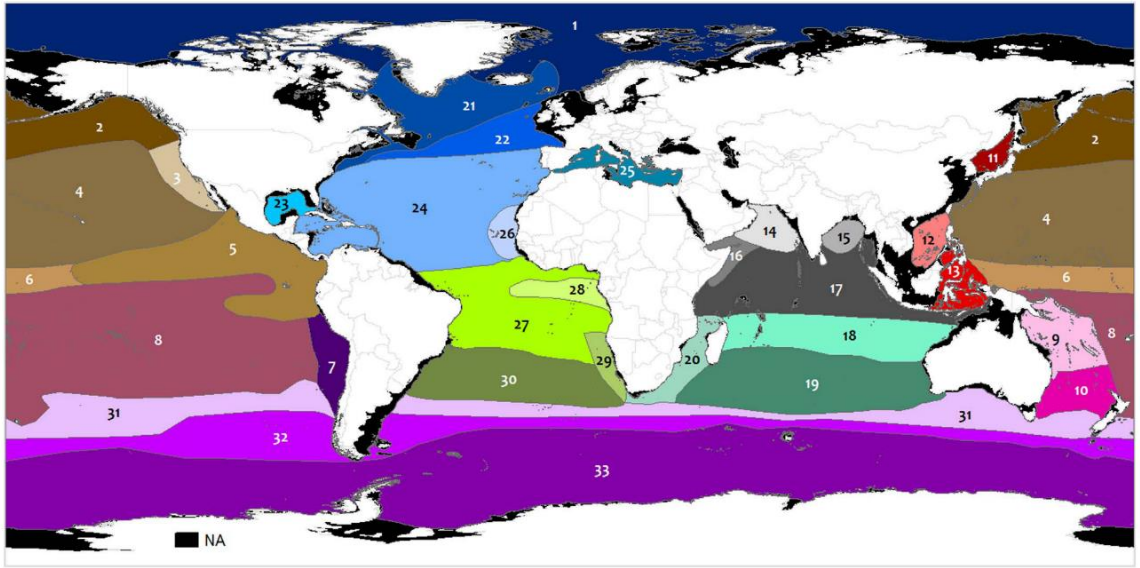


Fig. 4. Proposed mesopelagic ecoregions of the world's oceans. The numbers are simply for reference, and relate to the geographical names used in Table 1. Areas with depths less than 200 m shaded in black.

Sutton TT, et al. Deep Res Part I
Oceanogr Res Pap. 2017;126: 85–102

Biotic partitioning

Effects of topography

H.O. Fock et al. / Deep-Sea Research I 51 (2004) 953–978 955

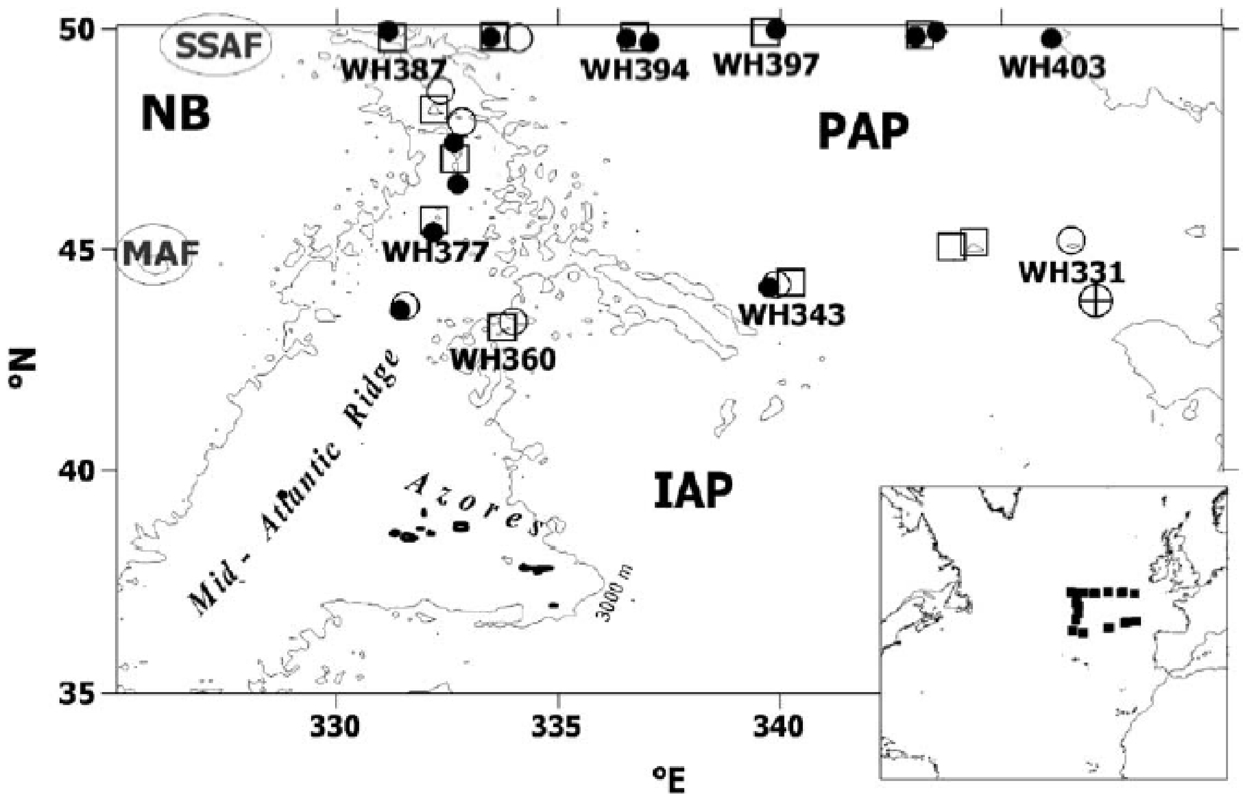


Fig. 1. Trawling stations, topography and location of fronts. Frontal systems as indicated by the literature: Position of Mid-Atlantic Front (MAF) and Southern Sub-Polar Front (SSAF) after Caniaux et al.(2001). Black dots indicate hauls <1000 m depth, circles hauls from 1000 to 2000 m depth, and squares hauls >2000 m. Station names at intervals, full account in Table 1. The encircled cross indicates a reference station from Roe et al.(1984). Insert picture shows position in North Atlantic. Topography and longitudinal scale obtained from http://topex.ucsd.edu/marine_topo/mar_topo.html. PAP—Porcupine-Abyssal Plain, IAP—Ibero-Abyssal Plain, NB—Newfoundland Basin. Depth contour at 3000 m.

Biotic partitioning

Effects of topography

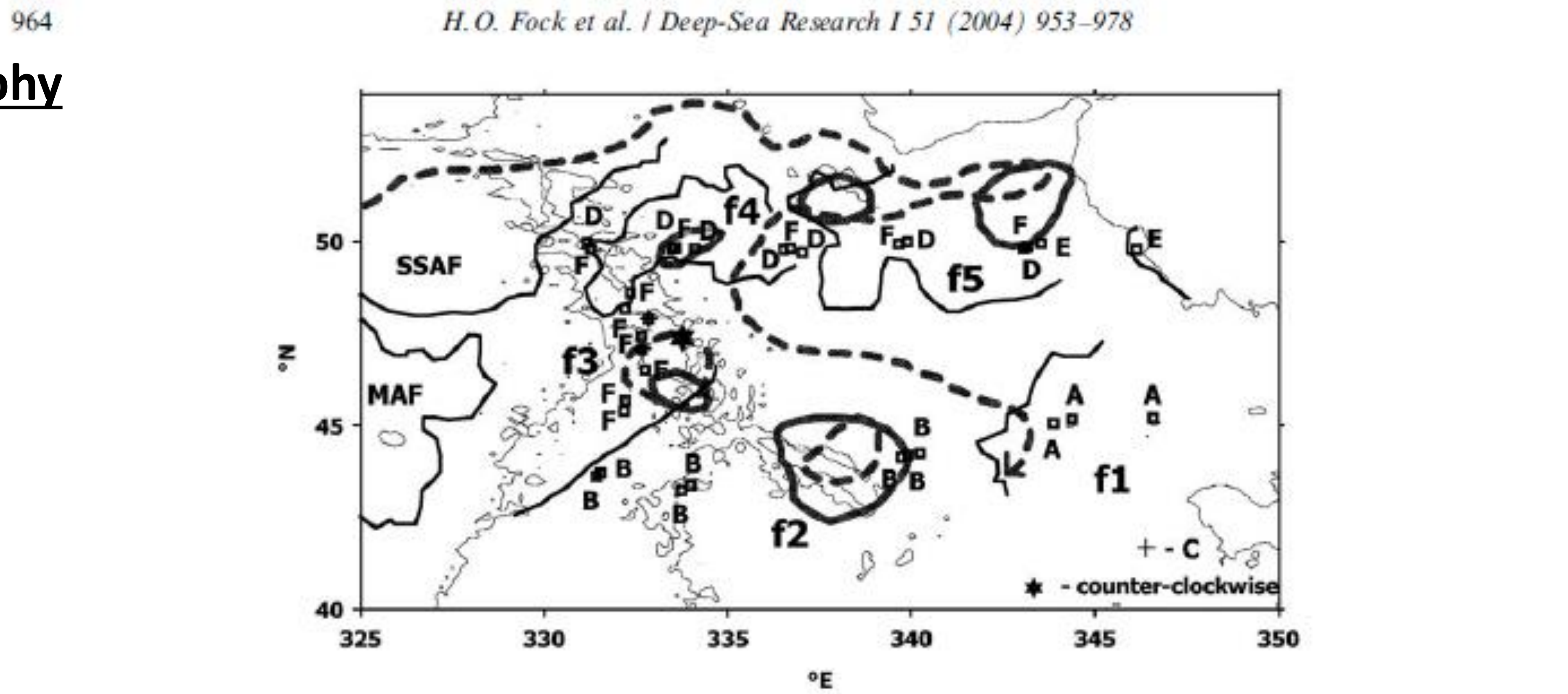
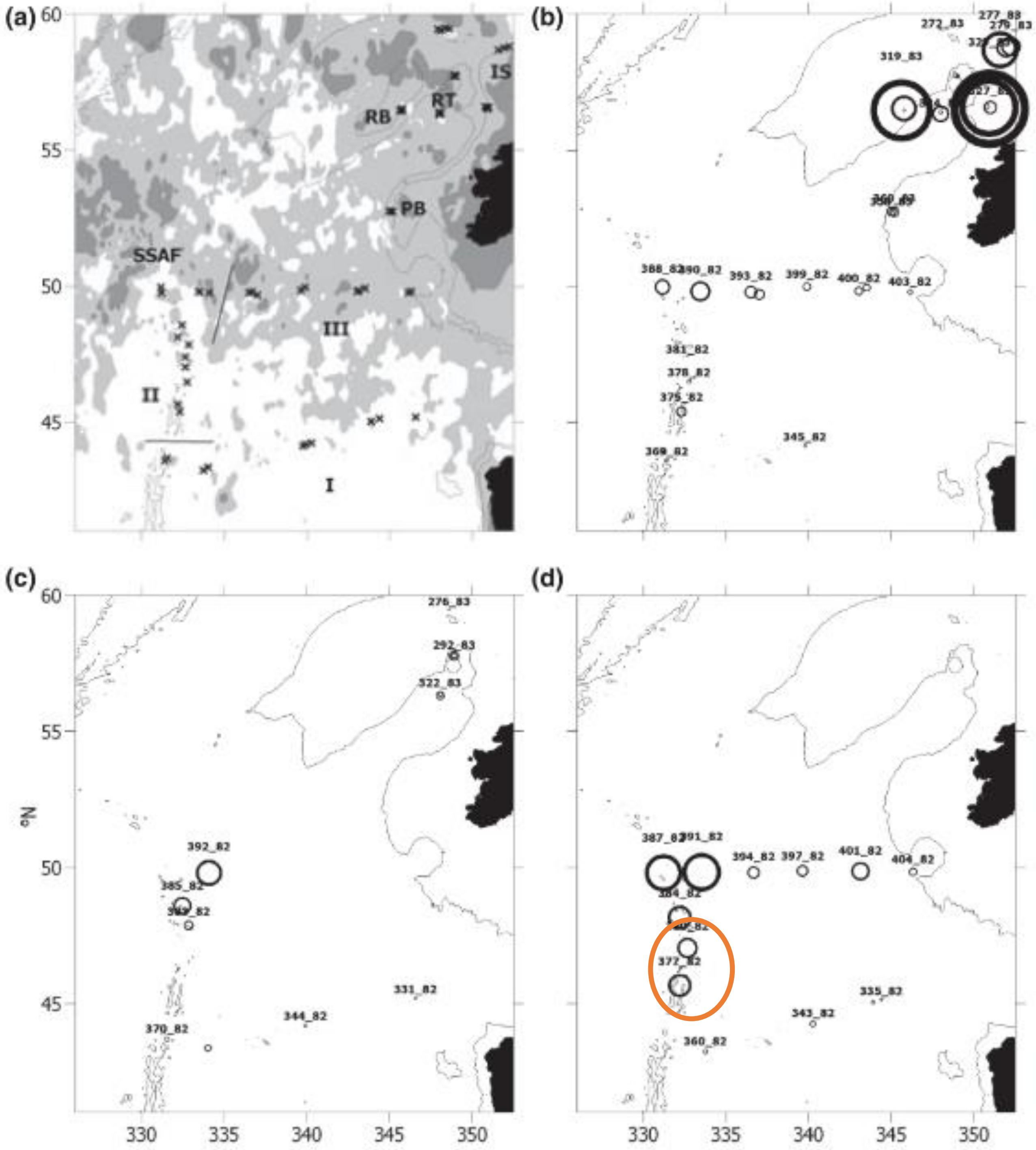


Fig. 7. Synthesis of hydrography and cluster distribution in 1982, compared to recent current investigations from 1993–2001. Cluster denotation after Table 1, water mass denotation according to Fig. 4 and water mass delimitation (bold black lines) after Fig. 5 A. Bold grey streamlines indicate clockwise recirculation cells at thermocline depth (600 m), broken thin grey streamlines indicate flow patterns at about 1750 m, either as recirculation cells or non-recirculating southward flow (arrow tip). East of the non-recirculating flow counter-clockwise streamlines appear. Streamlines partially redrawn from Bower et al. (2002). Asterisk indicates counter-clockwise deep recirculation for f3. The 600m-recirculation for f3 re-appears in an analysis of Lavender et al. (2000, Fig. 2).

Biotic partitioning

Fig. 1. Geographic presentation of sampling stations and results. (a) Sampling stations (X) and surface chlorophyll contours (shading steps) at 0.7 and 2.8 mg*m^{-3}, derived from CZCS-climatological spring image 1979–1986 (April-May-June). Images were obtained from http://seawifs.gsfc.nasa.gov/ SEAWIFS/ from the Nimbus 7 – Coastal Zone Colour Scanner archives (CZCS) and digitised. Surface production patterns serve a good proxies for regional oceanography (Longhurst, 1998). X = sampling stations. Station ID's according to Table 1; (b) Mesopelagic biomass densities; (c) Bathypelagic biomass densities; (d) Abyssopelagic biomass densities. For (b–d) bootstrap densities in g m^{-2} for 1000 m water column excluding *Cyclothone* spp. (Table 1), linear scaling. Not all station ID's indicated. SSAF, Southern Subarctic front; Area categories: I–III = regions I to III; IS = Irish Shelf; PB = Porcupine Bank; RB = Rockall Bank; RT = Rockall Trough



Fock HO, Ehrich S. J Appl Ichthyol. 2010;26: 85–101.

Longitudinal gradients – bathypelagic diversity

Temperature gradient and seasonality gradient

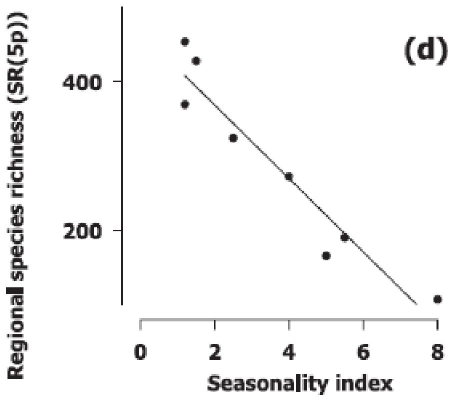


Figure 3 Latitudinal gradients in local (SL) and regional (SR) species richness and SL asymmetry. Lower panel, SL asymmetry; middle panel, SL and locally weighted scatterplot smoothing (LOESS) fit; upper panel, SR. SL asymmetry is calculated as the latitudinal fitted value minus the latitudinal mean for both hemispheres in 2° steps. SR values at different accumulation levels, i.e. thin line = three samples pooled (3p), bold line = five samples pooled (5p). Squares for SR indicate extrapolated values, arrow indicates values rescaled to larger sample size for the southernmost zone. ACC, Antarctic Circumpolar Current; EC, Equatorial Counter Current; NEC, North Equatorial Current; SEC, South Equatorial Current; SF, Subpolar Front; STC, Subtropical Convergence.