7.3 The Continental Shelf and Slope

J.P. Castello, M. Haimovici, C. Odebrecht, and C.M. Vooren

The influence of the Subtropical Convergence (STC), with marked seasonal latitudinal displacement, characterizes the southern Brazilian continental shelf and slope regions (29^0-34^0 S) as a biogeographic transition zone (Sharp 1988) between the large neritic areas of Patagonia and tropical Brazil. The composition and abundance of species, the pelagic structure, the spatial distribution of communities and their trophic interactions, as well as biological production are largely controlled by the seasonal dominance of distinct water masses over shelf and slope. Coastal and shelf break upwelling of deep Subtropical Water (STW) (South Atlantic central water) is frequent in the spring/summer and winter/spring, respectively (Lima and Castello 1995). The influence of Subantarctic and Tropical Water is greatest in the winter and summer, respectively, though waters of subantarctic origin may also rise during the summer along the southernmost shelf break regions (Fig. 7.3.1). Freshwater runoff from the La Plata River and the Patos Lagoon become important in the winter and spring. Particularly between Rio Grande and Chuí, oceanographic conditions favour high biological production, which results in a considerable, still almost unexploited biomass of small pelagic fishes (Castello and Habiaga 1982; Lima and Castello 1995) and highly productive, but now overexploited, demersal fishery resources (Haimovici et al. 1989a; IBAMA 1993). During most of the year, the thermal front on the western side of the STC provides a suitable habitat for pelagic sharks, tunafish, and thelike. Together, pulsed sub-surface coastal upwelling, onshore Ekman transport, and large-scale influence of continental runoff seem to sustain favourable conditions for fish spawning grounds and larval survival.

Pelagic Production

Owing to the influence of nutrient-rich Subantartic Water (SAW) and freshwater runoff from the Patos Lagoon and La Plata River, chlorophyll *a* and primary production rates are highest in the late winter and spring. Although outflowing freshwater generally has low nitrate concentrations, owing mainly to in- or nearshore phytoplankton uptake (Ciotti et al. 1995; Abreu et al. 1995a), nearshore bottom turbulences add nutrients to the euphotic zone (Odebrecht and Djurfeldt 1996) indicating that recycled nutrients may efficiently return to the water column. The influence of SAW on biological production occurs especially over the southern central shelf, where horizontal and vertical fronts are related to areas of the highest

integrated chlorophyll *a* concentrations (>100 mg m^{-2}; Ciotti et al. 1995). In the summer, the southward displacement of the oligotrophic Brazil Current leads to the lowest chlorophyll *a* and primary production rates. During this period, sporadically high chlorophyll *a* values and/or primary production rates depend on the upwelling intensity of nutrient-rich STW and the mixing regime, with high chlorophyll *a* concentrations occurring at sub-surface (Odebrecht and Djurfeldt 1996) or surface waters (Hubold 1980a). Interannual differences between phytoplankton chlorophyll *a* concentrations in shelf waters are strongly determined by continental runoff, which seems to be a function of the El Niño-Southern Oscillation cycle (ENSO).The highest chlorophyll *a* concentrations off southern Brazil coincide with a large freshwater outflow after periods of strong El Niño events in the Pacific Ocean (Ciotti et al. 1995). In addition, changes in the intensity of the Malvinas Current, probably as a consequence of climatic disturbances related to the ENSO phenomenum, may affect the variability of primary production from year to year.

A first evaluation of primary production data suggests moderate to high mean annual primary production rates (160 g C m^{-2} y^{-1}; Odebrecht and Garcia, Sect. 6.7) which probably sustain relative high secondary production (Cushing 1988). The high winter/spring biomass of zooplanktophagous (i.e. *Engraulis anchoita*), benthophagous, and predatory organisms, many of which, owing to the northward shift of the STC and the presence of SAW, migrate during this period from the south, supports this notion. Among the over 40 species of the pelagic necton community of the continental shelf, the fishes *Engraulis anchoita*, juvenile *Cynoscion guatucupa*, *Trichiurus lepturus*, and the squid *Loligo sampaulensis* are the most characteristic (Mello et al. 1992). Biomass estimates (in 1000 tons) for *Engraulis anchoita* range from 35 to 1928 in the summer and winter (Lima and Castello 1995), for *Trichiurus lepturus* from 3 to 30 in the winter and spring (Haimovici et al. 1996), and for *Loligo sanpaulensis* from 1.2 to 3.5 in the fall and spring (Andrigueto and Haimovici 1991). Over 50 species of cartilaginous fishes (mostly benthic feeding sharks, angel sharks, rays, and skates) and over 150 species of bony fishes (including 11 species of sciaenids) amount to over 80% of the total biomass, making up the demersal fish community of the shelf. Biomass estimates based on bottom-trawl surveys range from 43 000 to 96 000 tons for cartilaginous fishes (Vooren, Sect. 6.16) and from 137 000 to 340 000 tons for bony fishes (Haimovici et al. 1996) in the fall and winter/spring, respectively.

Fig. 7.3.1. Distribution of surface water masses over the shelf and vertical profiles at different latitudes duringthe winter (**A**) and summer (**B**). Coastal water (*CW*); South Atlantic Central Water (*SACW*); Tropical Water (*TW*); Subantartic Water (*SAW*); Antartic Intermediate Water (*AIW*); mixed Coastal Water with either SAW or TW (*MCW*). Mean ranges of chlorophyll *a* concentrations are given for some water masses

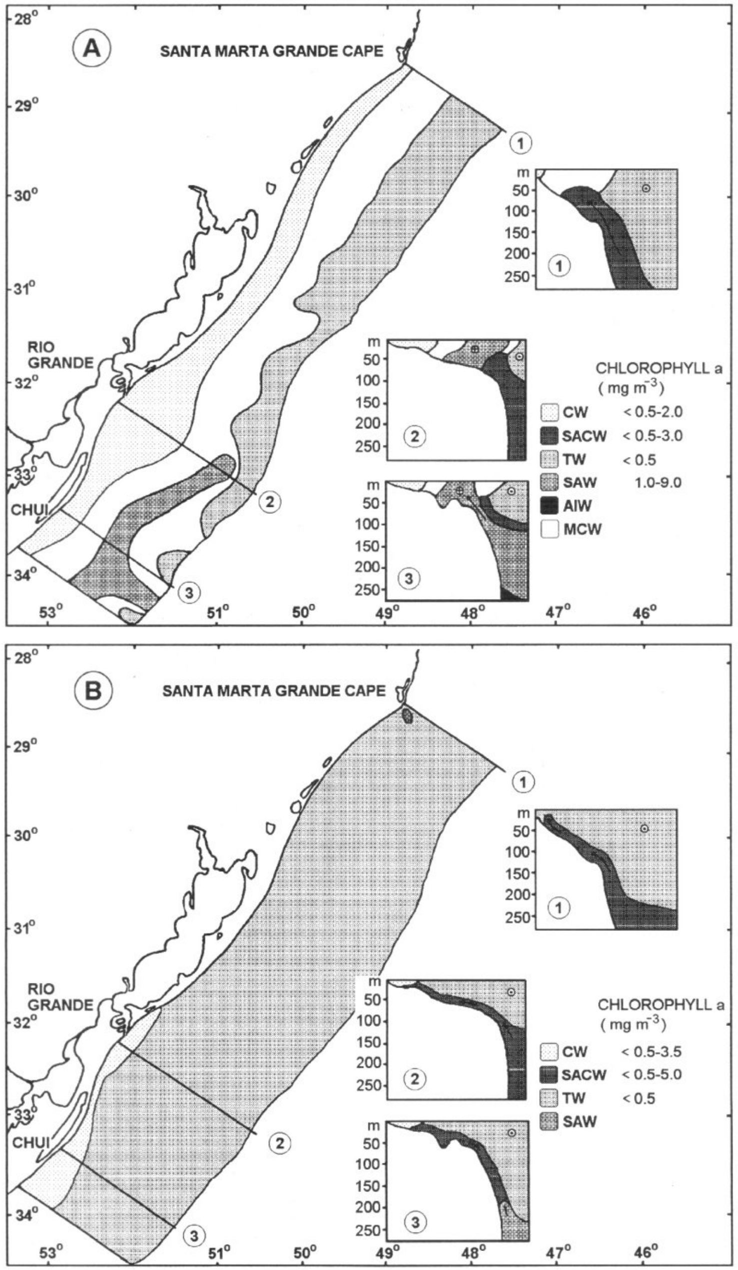

Fig. 7.3.1.

Biomass maxima of bony fish are associated with cold (<12°C) SAW of the coastal branch of the Malvinas Current over the central shelf and/or with the oceanographic front (>17°C) formed at the western side of the STC (Fig. 7.3.1). In general, demersal teleost diversity and species richness decrease with depth. The much lower abundance of bony fish over the upper slope than on the shelf (Haimovoci et al. 1994a) appears to be related to a poor benthic fauna.

In summer, the biomass of larger organisms is lower and is mostly composed of juvenile sciaenids, mainly *Trichiurus lepturus*, *Cynoscion guatucupa*, *Umbrina canosai*, angel sharks, and rays. During this season, the inner shelf areas form important nursery grounds for young of the year *Engraulis anchoita*, juveniles of commercially important bony fishes, and the neonates of cartilaginous fishes such as *Rhinobatos horkelii*, *Sphyrna lewini*, and myliobatid rays.

Pelagic Trophic Relations

The size structure of the pelagic community and the trophic interactions are largely determined by the size of primary producer species (Ryther 1969; Pomeroy 1974). Large primary producers (microplankton) give rise to shorter, less complex food webs with more efficient energy transfer, whilst small-celled (pico-nanoplankton) based communities display long and complex food webs with inherently inefficient energy transfer.

Large, single, centric diatoms or long chains of small-celled species are associated with high chlorophyll *a* values over the shelf during the late winter and spring. A considerable bacterial biomass, abundance of protozooplankton, and intense grazing activity by flagellates and ciliates point towards a complex microbial food web during periods of high phytoplankton biomass (Abreu, Sect. 6.6). The high phytoplankton biomass also supports a rich and abundant pelagic shelf fauna. Copepods are the dominant zooplankters (max. concentration of 2000 org. m^{-3}), but cladoceran and cold water euphausiaceans are also important. The dominance of planktophagous pelagic fish, like *Engraulis anchoita*, emphasizes the importance of short food chains during this period. Early larval stages (4-12 mm SL) of *Engraulis anchoita* feed on starch grains probably related to phytoplankton (Bursa 1968), as well as on nauplii, spores of fungi, and tintinnids. With increasing larval size (> 12 mm SL), copepods assume a more important part of the diet (Freire 1995). Calanoid copepods (*Calanus australis*, *Calanoides carinatus*, *Temora stylifera*, *Oncaea* sp., *Microsetella* sp.), euphausiacean (*Euphausia similis*) and hyperid amphipods comprise up to 90% of the diet of adult *Engraulis anchoita* (Schwingel and Castello 1995). Paralarvae and juveniles of the Argentinean squid *Illex argentinus* also feed on copepods and euphausids (Santos 1992; Vidal 1994b). Other zooplanktophagous species include the squid *Loligo sanpaulensis*, *Anchoa marinii*, *Trachurus lathami*, and juveniles of *Cynoscion guatucupa* and *Trichiurus lepturus* (Haimovici et al. 1996). Large individuals of *Trichiurus lepturus*, adult *Cynoscion guatucupa* (Vieira 1990; Haimovici et al. 1996), *Pagrus pagrus* (Capítoli and Haimovici 1993), *Galeorhinus galeus*, and the skates *Sympterigia acuta* and *Sympterigia bonapartei* prey on small fishes like *Engraulis anchoita*, *Paralonchurus brasiliensis*, and *Symphurus jenynsi* (Queiroz 1986). Large icthyophagous pelagic predators include the bluefish *Pomatomus saltatrix* (Haimovici and Krug 1992), angel sharks of the genus *Squatina*, and *Raja castelnaui*, which feeds both on pelagic and demersal fishes and squid. The feeding activity of other large predators, like the porpoise *Pontoporia blainvillei* and the sea lion *Otaria flavescens*, is largely restricted to coastal waters (Pinedo 1982). Over the outer shelf, pelagic zooplanktophagous species are represented by *Maurolicus muelleri*, myctophids, gonostomatids, juvenile *Merluccius hubbsi*, *Brama* spp., *Loligo sanpaulensis*, *Ornithoteuthis antillarum*, and *Illex argentinus*, which also preys on small pelagic and mesopelagic fishes (Santos 1992). Large ichthyophagous benthic fishes include *Galeorhinus galeus*, *Genypterus brasiliensis*, and *Polyprion americanus* which feed on young *Merluccius hubbsi* and *Illex argentinus* but also ingest macrocrustaceans. Large ichthyophagous pelagic predators, like the migratory *Xiphias gladius*, prey on *Illex argentinus* and other ommastrephids (Mello 1992), which also play an important role in the diet of *Thunnus obesus* and *Thunnus alalunga* (Santos and Haimovici, unpubl.), whilst *Thunnus albacares* preys on *Brama* sp., squids, and hyperid amphipods (Vaske 1992; Fig. 7.3.2).

In contrast, principally small primary producer organisms (picoplankton) compose the lower phytoplankton biomass during the summer (Odebrecht, unpubl.) when phytoplankton and bacterial carbon sources tend to be of similar magnitude. The pelagic community is more diverse than during the colder months and gives rise to complex feeding interactions, which is characteristic of oceanic oligotrophic areas where most zooplankton and all necton depend on secondary food sources (Cushing 1989; Legendre and Le Fèvre 1995). Filter feeders, like the Cladocera species *Penilia avirostris* and Thaliaceae, are abundant and consume bacteria and picoplankton. The large biovolume of Thaliaceae is common in subtropical seas because intensive grazing of large populations on small particles leads to fast growth. Planktonic molluscs (pteropods) feed on small particles, phytoplankters, protozoans, and zooplankters which adhere to their external mucus produced in the mantle cavity or in the foot (Parsons et al. 1984). The Euphasiaceae present diverse feeding mechanisms, like filter-feeding or "food basket" feeding. Practically all coelenterates are carnivores and prey on plankters, small fishes, and/or components of the necton. Zooplanktophagous fishes, like *Peprilus paru*, young *Trichiurus lepturus*, *Balistes capriscus*, *Cynoscion jamaicensis*, and the benthophagous

Ctenosciaenea gracilirrhus arrive from the north, whilst other ichthyophagous and/or benthic feeding species, including *Pomatomus saltatrix*, adult *Umbrina canosai*, *Cynoscion guatucupa*, *Micropogonias furnieri*, *Pagrus pagrus*, and *Mustelus schmitti* migrate southward. Owing to the southward migration of *Galeorhinus*, necton abundance decreases in slope regions, though dense schools of the skipjack tuna (*Katsuwonus pelamis*), which feed heavily on macro-zooplankton like *Euphausia similis*, the mesopelagic fish *Maurolicus muelleri*, and squids (Vilela 1990), arrive from the north (Fig. 7.3.2; Vilela and Castello 1991). Between November and May, large flocks of sea birds, like *Puffinus gravis*, *Sterna hirundo*, *Procellaria aequinoctialis conspicillata*, and *Diomedea chlororhynchos* (Chiaradia 1991), are associated with schools of *Katsuwonus pelamis* over the outer shelf. The rejected small bony fish from bottom-trawl fishing activities (Haimovici and Palacios 1981; Haimovici and Mendonça 1996) also provide an important food source for sea birds over the inner shelf (Vooren and Fernandes 1989).

Pelagic-Benthic Interactions

Pelagic-benthic interactions are either associated with the life-cycle of species with both planktonic and benthic stages or are related to their trophic behaviour. Trophic interactions may be bi-directional since either benthic organisms may benefit from sedimentation of particles from the water column or demersal and nectonic organisms may feed on the benthic fauna. Also, diel migrations favour an increase of pelagic-benthic interactions. For example, *Illex argentinus* feeds during the night at the surface but rests during the day near the bottom, where it is preyed upon by *Polyprion americanus* (Santos 1992) and probably by *Galeorhinus galeus*. Benthic food chains appear to be especially important over southern shelf regions, which coincides with intense bottom-trawl fishing (Haimovici et al. 1989a). Here, the coastal branch of the Malvinas Current supports high primary productivity, and areas with sandy and muddy bottoms favour an abundant invertebrate fauna of polychaetes. Among the benthophagous species, juvenile and adult *Umbrina canosai* (Haimovici et al. 1989b), *Micropogonias furnieri*, *Myliobatis* spp., *Sympterigia* spp., *Netuma* spp., *Mustelus schmitti*, *Raja* spp., and *Urophycis brasiliensis* are dominant over the shelf. Depending on the size of predators, the shrimps *Artemesia longinaris* and *Pleoticus muelleri*, the crabs *Portunis spinicarpus* and *Callinectes* sp., the bivalve mollusc *Solen tehuelches*, and a variety of polychaetes,

Fig. 7.3.2. Main feeding habits and seasonal movements of principal necton species of inner and outer shelf and upper slope regions

isopods, amphipods, and cumaceans are the principal prey in shallow coastal waters (Queiroz 1986). Benthic feeding fish species of the outer shelf include *Urophycis mystaceus*, *Coelorhincus marinii*, and *Helicolenus lahillei*. Although many species feed exclusively on the epi- and infaunal organisms, some important species, including adults of *Cynoscion guatucupa* (Viera 1990) and *Pagrus pagrus* (Capítoli and Haimovici 1993), prey on both benthic and pelagic organisms.

U. Seeliger C. Odebrecht J. P. Castello (Eds.)

Subtropical Convergence Environments

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With 66 Figures

Springer

Dr. Ulrich Seeliger
Dr. Clarisse Odebrecht
Lic. Jorge Pablo Castello

Department of Oceanography
Universidade do Rio Grande
96201 Rio Grande, RS
Brazil

ISBN 3-540-61365-X Springer-Verlag Berlin Heidelberg New York

Library of Congress Cataloging-in-Publication Data

Subtropical convergence environments : the coast and sea in the southwestern Atlantic / Ulrich Seeliger, Clarisse Odebrecht, Jorge Pablo Castello (eds.).
p. cm.
Includes bibliographical references and index.
ISBN 3-540-61365-X
1. Coastal ecology--South Atlantic Ocean. 2. Marine ecology--South Atlantic Ocean. 3. Marine biology--South Atlantic Ocean. 4. Biological diversity--South Atlantic Ocean. I. Seeliger, U. (Ulrich), 1944- . II. Odebrecht, Clarisse, 1952- III. Castello, Jorge Pablo.
QH93.6.S83 1997
574.5'2636'091636--dc20 96-32225

Cover design: Design & Production, Heidelberg
Typesetting: K. Darms, Bevern
SPIN 10519611 31/3137 5 4 3 2 1 0 - Printed on acid-free papier