Phytoplankton Patterns and Processes in a Tropical-Subtropical Transition Region: Santa Catarina Coast, Southern Brazil

Leonardo R. Rörig, Marcio da Silva Tamanaha, Graziela da Rosa Persich, Carlos A. França Schettini, and Eliane C. Truccolo Schettini

Abstract The coast of Santa Catarina state is 561 km long and presents varied features and ecosystems. Bordered by the states of Paraná to the north and Rio Grande do Sul to the south, the coast of Santa Catarina shows a clear transition between these two neighboring states. In the coastal zone, this transition is marked by the limit of mangrove distribution (latitude 28°30′S) and the presence of the Cape of Santa Marta Grande, which induces upwelling and creates important oceanographic changes that affect the continental shelf. The Santa Catarina coast is one of the most important fishing regions of Brazil and contains 95% of the country's mariculture. Phytoplankton of the neritic zone presents considerable seasonality, as evidenced by moderate diatom blooms in the spring, reduction of phytoplankton biomass in the summer, and increased importance of dinoflagellates in the winter, patterns associated with peculiarities of local oceanography. Blooms of *Trichodesmium* spp. are also seasonal from early spring to late summer. Various estuaries impose strong influence over these seasonal patterns, forming estuarine or fluvial plumes where phytoplankton biomass increases at any time of the year. The high degree of pollution, most likely associated with climatic and oceanographic anomalies in some areas, has resulted in unusual blooms of diatoms, e.g., *Pseudo-nitzschia* spp. and *Amphitetras antediluviana*, and dinoflagellates, e.g., *Dinophysis*

L. R. Rörig (✉) · G. da Rosa Persich
Laboratório de Ficologia (LAFIC), Universidade Federal de Santa Catarina (UFSC), Florianópolis, SC, Brazil
e-mail: leonardo.rorig@ufsc.br

M. da Silva Tamanaha
Laboratório de Ficologia, Universidade do Vale do Itajaí (UNIVALI), Itajaí, SC, Brazil
e-mail: mt@univali.br

C. A. França Schettini · E. C. Truccolo Schettini
Laboratório de Hidrodinâmica Costeira, Centro de Tecnologia e Geociências, Departamento de Oceanografia, Universidade Federal de Pernambuco (UFPE), Recife, PE, Brazil

M. S. Hoffmeyer et al. (eds.), *Plankton Ecology of the Southwestern Atlantic*,
https://doi.org/10.1007/978-3-319-77869-3_13

spp., posing a risk to both local ecology and mariculture. On sandy beaches, surf diatom blooms are quite frequent, especially *Asterionellopsis glacialis* sensu lato. The surf diatom *Anaulus australis*, which occurs along the entire Brazilian coast, alternating with *A. glacialis*, has its southern limit of distribution in Santa Catarina. These and other peculiarities characterize the Santa Catarina coast as an area of abrupt ecological transition and, hence, a genuine hotspot for ecological studies based on phytoplankton. This chapter reviews published data, including theses and difficult-to-access publications, in an attempt to characterize these transitional features but also to highlight emerging patterns to allow a greater understanding of western South Atlantic pelagic ecology.

Keywords Brazil · Santa Catarina · HAB · Microalgae · Bloom

1 Study Area

1.1 Physiography

The coastline of Santa Catarina in Southern Brazil (from latitude 25°58′S to 29°19′S) is 531 km long and consists of varied features, including bays, coves, rocky shores, extensive sandy beaches, islands, estuaries, and coastal lagoons (Fig. 1). Bordered by the states of Paraná (PR) to the north and Rio Grande do Sul (RS) to the south, Santa Catarina (SC) presents a clear transition between the coastal landscapes typical of these two neighboring states. The north and central portions (from 25°58′S to 28°36’S) present a complex of uplands and cliffs that reach the sea, forming rocky headlands that alternate with sandy beaches. Babitonga Bay, which is located at the extreme north end, harbors one of the more extensive and rich mangroves of Brazil. From this sector to the mouth of the Imaruí Lagoon (Laguna City, 28°29′S), the coastline is characterized by relatively short sandy beaches, coves and rocky shores, outlets of medium and small rivers, and the Island of Santa Catarina, which forms two large shallow bays on its western side, facing the continent. The largest river in this region is the Itajaí-Açu River (26°54′S) whose plume generally drifts north-northeast and influences the sediment flow of the adjacent continental shelf. From the Imaruí Lagoon toward the south, the coastline becomes straight and is characterized by extensive and exposed sandy beaches, rivers with relatively small basins, and the presence of a broad coastal plain where a coastal lagoon system extends. The limit of distribution of mangroves along the southeast coast of South America is located in the estuarine part of Imaruí Lagoon (28°30′S). From this point southward, salt marshes begin to dominate the estuarine and lagoon fringes. The Cape of Santa Marta Grande (CSMG, 28°36′S) is located near this area. This geographical feature is also an important geographical accident that determined changes in the landscape of Santa Catarina, as well as the coastline, which shifted toward a more southeasterly direction. In addition, the position of the

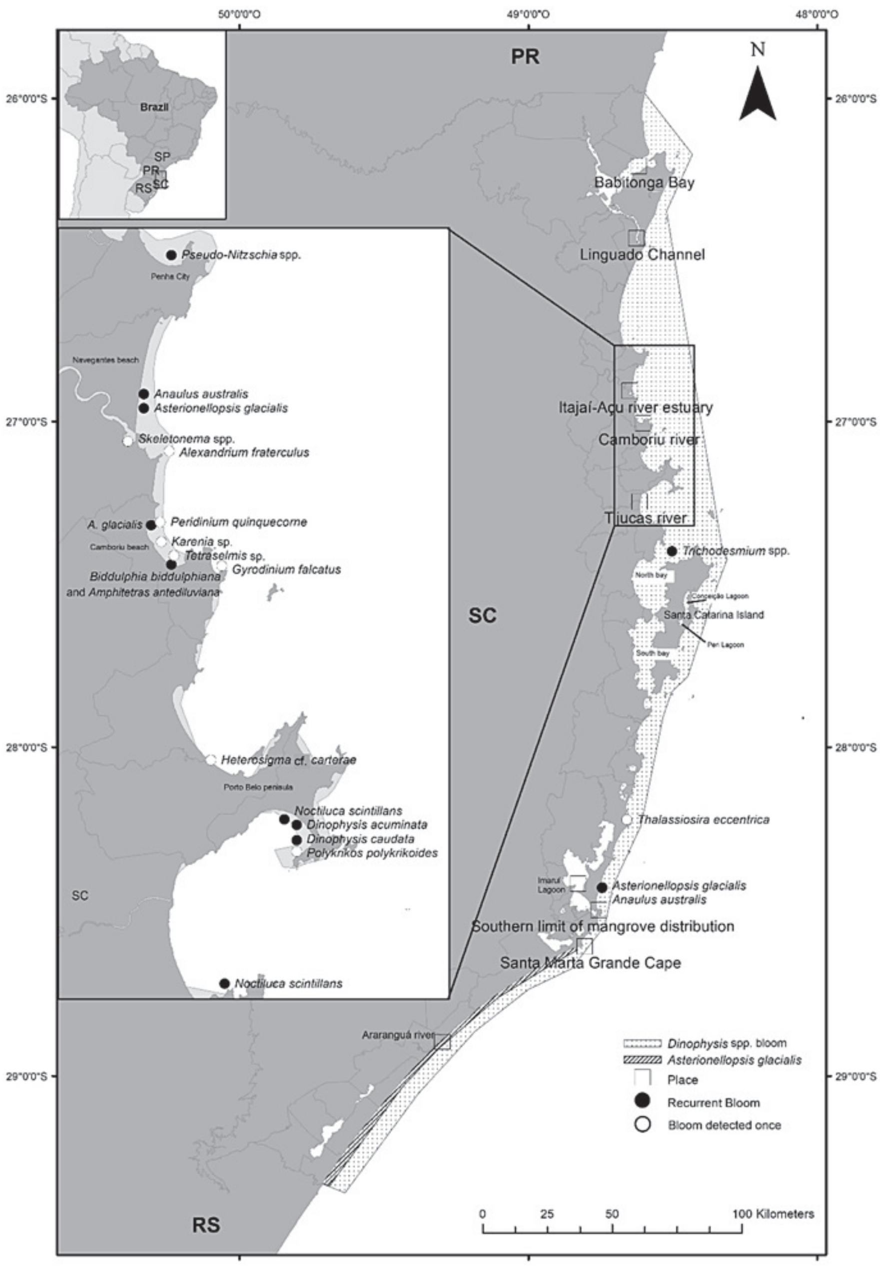

Fig. 1 Location of the coast of Santa Catarina in Southern Brazil with indications of the main occurrences of phytoplankton blooms

Table 1 Features of the southern states of Brazil coast

State coast	Latitude	Coast extension (km)	N° inlets/estuarine systems	N° inlets/100 km
SP	23°22′S–25°18′S	622	43	6.91
PR	25°18′S–25°58′S	98	7	7.14
SC	25°58′S–29°19′S	531	45	8.47
SC north	25°58′S–28°36′S	411	41	9.97
SC south	28°36′S–29°19′S	120	4	3.35
RS	29°19′S–33°44′S	623	4	0.67

SP São Paulo, *PR* Paraná, *SC* Santa Catarina, *RS* Rio Grande do Sul

cape determines the occurrence of coastal upwelling, strongly influencing the physical and ecological characteristics of coastal and shelf waters. South of CSMG, the decreasing number of inlets or estuaries of small- and medium-sized rivers presents topography more akin to that of extreme Southern Brazil, while the northern portion is more similar to the southeastern Brazilian coast by the greater number of inlets (Table 1).

1.2 Physical Oceanography

The southeast continental shelf of Brazil (SEBCS, from 21.5°S to 34.9°S) is divided into three areas according to physiographic features and major oceanographic processes: the southern Brazilian shelf (SBS) from Chuí (34.9°S) to CSMG (28.5°S), the southern Brazilian bight (SBB) from CSMG (28.5°S) to Cabo Frio (23°S), and the Abrolhos-Campos Region (ACR) from Cabo Frio (23°S) to Cape São Tomé (21.5°S) (Castro and Miranda 1998). The continental shelf of SC is covered by SBS and SBB. The shelf break along SBB and SBS occurs at a depth of about 180 m, ending at a depth of 2000–2900 m (Ito et al. 2016), and the shelf width ranges between 105 km off CSMG and 260 km off Babitonga Bay. Offshore circulation is dominated by the Brazilian Current (BC), which flows southward (limited to the upper 500 m), advecting tropical water (TW, salinity >36.4, temperature > 20 °C) and influencing the shelf water masses during summer (Castro and Miranda 1998). During winter, a northward coastal current advects the Plata Plume water (PPW, salinity <33.5, temperature > 19 °C). During summer, northerly winds favor an upwelling process and advection toward the shore of the South Atlantic Central Water (SACW, salinity 34.6–36.2, temperature 8.7–20 °C), which occupies the bottom layer and reaches the surface between CSMG and Santa Catarina Island. Mainly from Santa Catarina Island northward, the contribution of local freshwater produces coastal water (CW, salinity <35 and temperature varying seasonally). Figure 2 shows block diagrams that indicate the spatial occurrence of these water masses.

The SC coast receives significant input of nutrients from discharges emanating from the Río de la Plata and the Patos Lagoon (Ciotti et al. 1995), as well as small

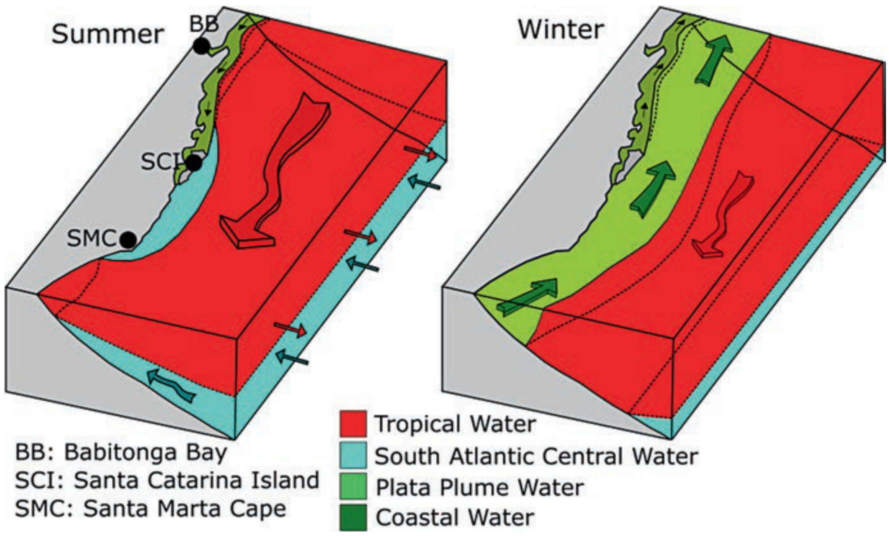

Fig. 2 Schematic block diagrams of the main distributions and currents of the water masses on the Santa Catarina continental shelf in summer and winter

contributions from local estuaries. Additionally, it is influenced by SACW upwelling directly in the coastal zone and from the external continental shelf. In winter, Campos et al. (1995) proposed that the mechanism responsible for pumping the SACW to the continental shelf involves the cyclonic meandering of the BC, inducing shelf break upwelling. During the summer, this process is combined with coastal upwelling from the northeast. The main coastal upwelling of SC occurs near the CSMG, but indications of small upwellings can be observed near coastal islands, especially in the case of both Santa Catarina and Arvoredo Islands (Rörig et al. 1997; Resgalla Jr. et al. 2004). These upwellings represent peculiarities of the SC coast, having the ability to induce special effects on local biological diversity and productivity (Aidar et al. 1993; Ciotti et al. 1995).

1.3 Regional Climatology

According to the Köppen Classification System, the climate of SC is humid subtropical, mesothermal, without a dry season (Cf), and with hot (Cfa) and temperate summers (Cfb) (Alvares et al. 2013; Pandolfo et al. 2002). Both temperature and precipitation present significant spatiotemporal variability, as determined by geographic position, relief characteristics, and atmospheric circulation systems acting in the region (Monteiro 2001; Grimm 2009a). Furthermore, significant variations occur on an interannual scale relative to El Niño/La Niña events (Grimm 2009b; Firpo et al. 2012).

The mean annual temperature in the region is 20 °C, with a winter (July) and summer (February) mean minimum of 10 and 31 °C, respectively (Pandolfo et al. 2002). Total annual precipitation is around 1100 to 1300 mm, but it can reach values up to 2300 mm (Grimm 2009a).

Northerly winds, mainly northeasterly, predominate along the year, followed by southwesterly winds, mainly in the fall and winter, with maximum velocities around 18 ms^{-1}. These northeasterly synoptic winds are generated by the Atlantic subtropical high (ASH), which predominates over the Atlantic Ocean. The components of southwesterly winds are strongly related to the passage of frontal systems across the region. Cold fronts pass through SC with an average monthly frequency of 3 to 4 (Rodrigues et al. 2004). These cold fronts strongly affect coastal wave climate and circulation and, consequently, the coastal ecology.

2 General Patterns of Coastal and Shelf Phytoplankton

Phytoplankton studies on the SC coast began in 1994, following the creation of the oceanography course at the Universidade do Vale do Itajaí (UNIVALI). Previously, only isolated studies reported on some estuaries and islands (e.g., Araujo et al. 1989; Odebrecht 1988; Cardoso et al. 1994). Some nationwide projects also conducted sampling at stations on the SC continental shelf and described general phytoplankton and primary production patterns, but without characterizing local specificities, owing to the degree of spatiotemporal spacing between samples (e.g., Brandini 1988; 1990a, b; Ciotti et al. 1995).

In 1994, a series of seasonal oceanographic cruises began in association with a project known as "Integrated Study of the Ecosystem of Itajaí-Açu River Estuary and Adjacent Coastal Zone" (FBB Project). It was developed by UNIVALI with funding from the Banco do Brasil Foundation (FBB) and support from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA). Cruises aboard the Diadorim research vessel (IBAMA) occurred in the spring and summer of 1994 and in the fall and winter of 1995. These crises consisted of a spatiotemporal assessment of water mass characteristics, chemical characterization, primary production, and phytoplankton analysis. The sampling area covered the internal platform up to about 50 m depth, focusing on the influence of Itajaí-Açu River discharge, the main river flowing to the coast of SC, as well as other smaller rivers between the latitudes of 26°30′S and 27°17′S (Carvalho et al. 1998).

The physical oceanography results of this project showed seasonally different situations for the region. In spring and summer, the water column was stratified with a strong thermocline, where northerly winds, especially northeasterly, cause SACW upwelling and southerly winds cause subsidence of coastal waters with thermocline deepening. During autumn and winter, the water column is predominantly homogeneous as a result of both coastal subsidence, owing to the greater magnitude and persistence of southerly winds, and by the advection of subantarctic waters, which are influenced by the contribution of the Río de la Plata and Patos Lagoon (Carvalho

Table 2 Primary productivity data of Santa Catarina coast (Brazil) during a seasonal cycle survey between 1994 and 1995

Season	Average surface irradiance (μmol m^{-2} h^{-1})	Average surface chlorophyll *a* (mg m^{-3})	Average surface photosynthesis (mgC mgChl *a* h^{-1})	Irradiance of maximum primary productivity (μmol m^{-2} h^{-1})	Primary productivity at optimum irradiance (mgC mgChl a^{-1} h^{-1})	n
Spring	1569	2.26	3.50	1008	6.12	6
Summer	1757	1.27	2.69	645	4.19	4
Autumn	879	0.83	3.14	716	3.70	4
Winter	1101	1.72	5.42	1101	7.58	8

L.R. Rörig, previously unpublished data

et al. 1998). These results corroborate previously defined features found in larger-scale studies along SCSB and guided a series of regional studies in chemical and biological oceanography.

For the first time, data on the primary production of phytoplankton were generated, and the main species occurring in the coastal zone were detected, as well as typical blooms (see below). A considerable part of the information from the FBB Project has not been published in international journals, and the data are only found in technical reports, monographs, and authors' databases.

Phytoplankton photosynthesis data per unit of chlorophyll *a* (photosynthetic efficiency) were generated by the ^{14}C method (Richardson 1987) at stations selected from a grid of 63. Using an in situ simulated system, surface samples were incubated in a gradient of irradiances to obtain preliminary data on the optimal irradiance for the phytoplankton community during each season of the year. Table 2 shows a summary of these previously unpublished data. Since they are average values, we can clearly see the seasonal differences in irradiance, chlorophyll a, and photosynthesis. The highest chlorophyll a values were recorded in spring, followed by winter and summer, with lower values in fall. Surface photosynthesis values were highest in winter, followed by spring, which could be associated with higher nutrient concentration. Apparently, photosynthesis was photoinhibited by surface irradiance in all seasons, except winter, when the maximum surface irradiance occurred. Thus, although the mean value was higher in winter than in spring, an integration of the data along the water column would probably show maximum values in spring because of the lower irradiance and photoperiod in winter (Pellens 1997; Rörig et al. 1998b). These values were higher than those recorded by other authors in samples from the SC continental shelf and from northern states (PR and SP, Table 3). Such differences may be related to the sampling region where data obtained in the FBB Project were from more coastal stations, even though chlorophyll a values were similar.

Two types of diatom blooms were detected in 1994. The first was a relatively strong diatom spring bloom with subsurface biomass peaks often associated with the thermocline or in the top 10 m of the water column. This bloom was dominated

Table 3 Primary productivity data from southern and southeastern Brazilian continental shelf off São Paulo, Paraná, and Santa Catarina states

Water mass	Average value of chlorophyll a (mg m^{-3})	Average value of photosynthesis (mgC mgChl *a* $^{-1}$ h^{-1})
Coastal water	2.9	4.24
Plata Plume water	0.46	2.0
Tropical water	0.21	3.59

Extracted from Gaeta and Brandini (2006)

by *Pseudo-nitzschia* spp., *Skeletonema tropicum*, *Chaetoceros* spp., *Bacteriastrum* sp., *Lauderia borealis*, and *Hemiaulus* spp., among others. The presence of dinoflagellates was more discrete, but *Prorocentrum* spp., *Protoperidinium* spp., and *Neoceratium* spp. were quite common. Another highlight was the considerable density of micro- and macrozooplanktonic organisms, even using phytoplankton nets (20 μm), indicating intense trophic flow.

The other bloom, detected simultaneously, but with patchy distribution, was composed of cyanobacteria *Trichodesmium* spp. The dominant species was identified at the time as *T. erythraeum* (Guimarães and Rörig 1997). Subsequent analyses suggested it to be *T. hildebrandtii* (Rörig et al. 1998a). *T. thiebautii*, a species already recognized as toxic at that time, was also detected, although rare. These blooms were easily visible on the surface of the water, forming in-line accumulations influenced by the wind (Langmuir circulation). White patches were revealed to be formed by senescent populations (Fig. 3c), and pale brown patches were formed by healthy populations. Frozen samples of the healthy populations developed a strong reddish color, suggesting the presence of phycoerythrin, an accessory pigment typical of marine cyanobacteria.

This positive buoyancy behavior in *Trichodesmium* spp. is a well-known phenomenon (Carpenter and Price 1977). Low levels of dissolved nitrogen in water cause trichomes to group into colonies and increase buoyancy by the action of intracellular gas vesicles. Once at the water-air interface, the colonies are susceptible to wind transport. Peripheral trichomes in the colonies remain photosynthetically active, while the internal ones, chlorophyll a is inactivated, and nitrogenase, responsible for N_2 fixation, is activated. Photosynthesis and nitrogen fixation are incompatible functions in the same cellular environment since oxygen produced by photosynthesis inactivates nitrogenase (Fay 1992). This ability of *Trichodesmium* spp. allows survival and proliferation in oligotrophic waters. Thus, this phenomenon results in a functional nitrogen link that fertilizes oligotrophic waters and promotes increases in biological productivity. In fact, in those blooms, biomass and diversity of other phytoplankton species and also zooplanktonic species were higher when compared to areas without *Trichodesmium* patches (Guimarães and Rörig 1997).

Previously, blooms of these cyanobacteria had only been recorded in the tropical northeastern region of Brazil (Satô et al. 1963) and on the coast of São Paulo (Gianesella-Galvão 2000). Despite this, it is likely that they always occurred in the

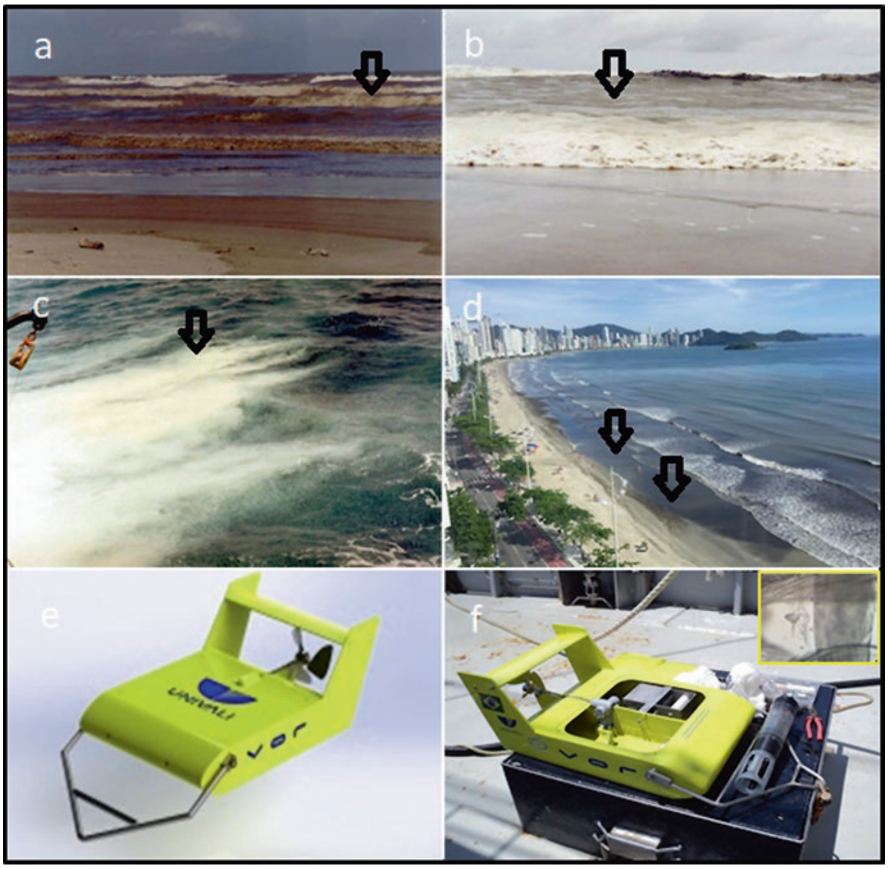

Fig. 3 Photographs of blooms (arrow) on the coast of Santa Catarina, Brazil, and the Towed Oceanographic Vehicle (VOR). (**a**) Bloom of the surf diatom *Asterionellopsis glacialis* on Rincão Beach. (**b**) Bloom of the surf diatom *Anaulus australis* on Navegantes Beach (kindly provided by Dr. Luis A. Oliveira Proença, IFSC, Florianópolis, Brazil). (**c**) Senescent bloom of *Trichodesmium* spp. near Arvoredo Island. (**d**) Bloom of invasive bryozoans and epibenthic diatoms on Camboriú Beach (kindly provided by Dr. Fernando Luiz Diehl – Acquaplan – Balneário Camboriú, Brazil). (**e**) VOR technical drawing. (**f**) VOR after operation; photo in detail at top right showing a *Neoceratium* sp. cell retained in the mesh

region and were never detected because of the absence of detailed studies. Evidence of this is revealed by the detection of such blooms every year since then between September and February in monitoring programs (CIDASC 2017). Although recurrent on the coast of SC, the origin of the *Trichodesmium* patches is in the most oceanic, oligotrophic waters associated with the Brazil Current. Their penetration toward the coast is associated with transport by wind and oceanic fronts. It is possible that *Trichodesmium* populations increase as they find phosphate-rich waters close to the coast related to small upwellings (Rörig et al. 1998a) or to continental inputs (Schettini et al. 2005), but they do not persist for long when entering less saline and more turbid coastal waters dominated by r-strategist species, such as diatoms. Even so, the inputs to biological productivity are abundant, as are the risks to mariculture and fish resources, as further studies have revealed toxicity associated with these patches (Proença et al. 2009; Detoni et al. 2016). Over the last years, in spring and summer, *Trichodesmium* patches were also recorded in the coastal region of Paraná (Siqueira et al. 2006) and Rio Grande do Sul (Silva et al. 2008).

FBB Project samplings also revealed general patterns for phytoplankton in summer, fall, and winter. In summer, a decrease in phytoplankton biomass was reported, especially in areas farthest from the coast. However, near the coast, the enrichment pulses generated by small upwellings and the contribution of fluvial discharge, owing to high regional rainfall, were able to sustain rich populations, especially diatoms. *Trichodesmium* patches also occurred, albeit less frequently (Rörig et al. 1998b).

Autumn showed the lowest chlorophyll a values (Table 2), probably from zooplankton grazing and strong water column stratification (Carvalho et al. 1998). It is important to highlight the occurrence of central diatoms of the genus *Coscinodiscus*, including *C. wailesii*, *C. gigas*, and *C. radiatus*. The large cell size of these species prevents grazing by most zooplankton, making them remnants of diatom populations that have developed since the spring of the previous year. It is possible that these populations are grazed by gelatinous organisms, such as siphonophores, salps, or cnidarians, which are common at this time in the region (Resgalla Jr. et al. 2005), and even fish (e.g., *Mugil* spp.). Another likely strategy is sinking so that they can act as food for benthic fauna or enter the debris chain.

The winter pattern was quite peculiar in that it showed an increase in the relative importance of dinoflagellates (Rörig et al. 1998b). A number of subsequent monitoring programs have shown that this greater importance of dinoflagellates in winter is a recurrent pattern (unpublished data from monitoring projects of UNIVALI and UFSC). It is likely that these populations originated from the greater influence of subantarctic waters in winter, which are richer in dinoflagellates (Islabão and Odebrecht 2011). Once on the coast of Santa Catarina, some dinoflagellate species probably find optimal conditions to form blooms, such as the presence of sites of lower turbulence and high nutrient concentration. It is precisely in this type of environment that mariculture, in particular mussels and oysters, was developed in the region, indicating that winter is a critical period for harmful algal bloom (HAB) monitoring.

These initial studies were fundamental in describing the general pattern of SC coastal phytoplankton. More systematic studies have confirmed these trends and support the idea that this region has heterogeneous and complex patterns in terms of abundance, diversity, and distribution of phytoplankton, as well as the occurrence of blooms. These data also supported the first major Brazilian HAB monitoring program established on the North Central Coast of SC (see below).

More recently, Becker (2014), in a comprehensive study involving phytoplankton and zooplankton on the SC continental shelf, highlighted the influence of estuarine discharges, coastal upwelling, and seasonal variations of water masses in structuring the planktonic community. It was evident from this study that the SC inner shelf undergoes dramatic annual variability with strong thermocline during summer and almost no stratification during winter when the influence of PPW is greater (Fig. 2). The highest abundances of diatoms and copepods were associated with the maximum chlorophyll *a* layers from SACW intrusions near the surface (Fig. 2). The intermittent upwelling and river plume events bring nutrients to surface layers. This surfacing of nutrients results in variation in phytoplankton size structure such that larger, or chain-forming, cells have an advantage that ends up influencing the size structure of copepods. If these enrichment processes do not occur, or are less frequent, either as a matter of time or place, the predominance of smaller phytoplankton (pico- and nanophytoplankton) determines longer trophic chains typical of tropical conditions. Becker (2014) also highlighted nutrient enrichment caused by the Itajaí-Açu River (latitude 26°54′S) and Babitonga Bay (latitude 26°10′S) and their influence on the biomass and composition of phytoplankton and zooplankton, as also pointed out in previous studies (Schettini et al. 1998; Resgalla Jr. 2009; Rörig et al. 2003). These data indicate that the combined influence of the Itajaí-Açu River plume and CSMG represents the major regional factor affecting the structure of plankton assemblage, often overlapping with the patterns defined by the seasonal influence of water masses.

3 Surf Zone Diatoms

The occurrence of dense diatom blooms or accumulations in the surf zone is a typical phenomenon of many exposed, intermediate to dissipative, sandy beaches (Talbot et al. 1990). The accumulations appear as neustonic, flocculent, and brownish patches at the inner surf zone and are also deposited on the beach face, representing intense autochthonous contributions of organic matter to the beach ecosystem with extremely high chlorophyll *a* concentration (Talbot and Bate 1988). These accumulations are mainly formed by a combination of resuspended epibenthic stocks deposited beyond the surf zone and special adaptations of the species involved (Talbot and Bate 1988). The increase of wave energy, as determined mainly by the passage of frontal systems, resuspends the stocks. Suspended cells release mucus allowing them to stick to wave foam and form patches. After a few days, the mucus properties change, and particles of suspended material adhere to cell masses, favoring sedimentation, and return to the original epibenthic position, as wave energy dissipates. In Brazil, surf diatoms accumulations are more common in the southernmost part of the country (RS coast) and also in the southern portion of SC state (Rörig et al. 1997; Odebrecht et al. 2010) where extensive exposed sandy beaches dominate the coastal landscape. However, these phenomena are also recorded along the entire Brazilian coast (Odebrecht et al. 2014). In SC, a 6 km stretch between headlands (Balneário Camboriú, 26°59′S) was the shortest beach where these accumulations were observed. Of the seven species that form this phenomenon around the world (Odebrecht et al. 2014), at least two occur in Brazilian beaches, and *Asterionellopsis glacialis* and *Anaulus australis* are part of it. Recently, molecular analyses have shown that the species traditionally identified as *A. glacialis* represents a complex of species (Kaczmarska et al. 2014). In this chapter, which reports works made before this discovery, the possible different species are grouped as *Asterionellopsis glacialis* sensu lato.

On the SC coast, accumulations of *A. glacialis* s.l. and *Anaulus australis* show different distribution patterns (Fig. 3a, b). *A. glacialis* s.l. occurs as an exclusive species on the beaches south of CSMG and co-occurs with *A. australis* on northern beaches, with monospecific or bispecific accumulations having different degrees of dominance among species (Rörig et al. 1997). This pattern of mixed accumulation has also been verified on beaches in the state of Paraná (Rezende and Brandini 1987) and in the northeastern part of the country (Tedesco et al. 2017). What draws attention to these data is the apparent limit of distribution of *A. australis* in CSMG. This species has neither been recorded on the coast of RS nor on the beaches of Uruguay and Argentina where only *A. glacialis* s.l. and *Attheya armata* have been recorded (Odebrecht et al. 2014). It is still not possible to assert what determines this limit of distribution, whether the physical barrier (lower temperature), as represented by the coastal upwelling south of the CSMG, or competition that would favor *A. glacialis* s.l. by its adaptation to the morphodynamic patterns of extensive beaches which lie south of this cape. In any case, this aspect reinforces the ecological transition that takes place on the southern Brazilian coast, as represented by the CSMG.

The beaches that are active for this phenomenon are usually close to river mouths or estuaries. In these areas, changes in sedimentation patterns, especially where dredging activities take place, can affect the cycle of surf diatoms, reducing, or even blocking, their occurrence. This is likely to occur, for example, at Cassino Beach near the Patos Lagoon estuary (RS) and at Navegantes Beach (SC), suggesting the wisdom of monitoring actions, given the central trophic importance of these blooms for regional fisheries, not only quantitatively but also qualitatively, as sources of essential fatty acids (Rörig et al. 2017a).

4 HAB Monitoring and Research on the Santa Catarina Coast

In the early 1990s, mariculture was established on the coast of SC, as an option to complement the income of artisanal fishermen, and it gradually became an important activity, changing the economic profile of the region. In this context, in 1995, UNIVALI began research at Armação do Itapocorói, in the city of Penha, to identify and monitor harmful algal blooms (Proença and Rörig 1995; Rörig et al. 1998b; Proença et al. 1998). In 1997, the first monitoring program of harmful algae and phycotoxins in Brazil began, and they consisted of identifying microalgae and analyzing phycotoxins with bioassays and high-performance liquid chromatography (HPLC). The program followed the model of Galicia, Spain, where UNIVALI researchers were trained under the guidance of the Spanish Oceanographic Institute (IEO), Vigo. After a few years, the methods were standardized for routine analyses of saxitoxins (paralytic shellfish poisoning – PSP), okadaic acid (diarrheic shellfish poisoning – DSP), and domoic acid (amnesic shellfish poisoning – ASP) (Hallegraeff et al. 1995). Subsequently, the monitoring was expanded to other mariculture-producing regions of SC with the participation of EPAGRI (Agricultural Research and Rural Extension Company of Santa Catarina), aiming to guarantee the sanitary quality of the shellfish.

The first effective results of this program came in 2001 when the microalga *Gymnodinium catenatum*, a PSP producer (Proença et al. 2001), was identified for the first time and isolated. In the following years, four potentially harmful taxa, including *Peridinium quinquecorne*, *Karenia* sp., *Tetraselmis* sp., and *Gyrodinium falcatus*, were recorded in Balneário Camboriú, SC (M. S. Tamanaha, unpublished data) (Fig. 1). In 2007, high biomasses of *Pseudo-nitzschia* spp. (> 40,000 cells L^{-1}, Tamanaha et al. (2008)) and *Alexandrium* cf. *tamarense* (Miotto and Tamanaha 2012) were recorded for the first time in SC. In the same year, the SC coast was affected by a bloom of *Dinophysis acuminata*, a potential DSP producer (unpublished data from UNIVALI Monitoring Program). According to official data (ANVISA), more than one hundred people were poisoned by contaminated mussels. At that time, the harvesting and consumption of shellfish were prohibited. It would be the first of many official ordinances recommending discontinuation of shellfish consumption, attesting to the program's effectiveness in regional food security. Both HAB and phycotoxin monitoring became part of the National Program for Sanitary Control of Bivalve Molluscs (PNCMB). This program defined maximum permitted limits for phycotoxins in shellfish meat at 0.8 mg 100 g^{-1} for saxitoxin, 0.16 mg100 g^{-1} for okadaic acid, 20 mg 100 g^{-1} for domoic acid, 1 mg 100 g^{-1} for yessotoxins, and 0.16 mg 100 g^{-1} for azaspiracid (Instrução Normativa Interministerial MPA/MAPA n ° 07/2012). These interinstitutional efforts culminated in December 2011 with the establishment of a website administered by the state inspection service. This provided a database where reports of phycotoxin analyses of almost all SC cultivation areas could be published (CIDASC 2017).

In August 2011, another bloom of *D. acuminata* was detected in Governador Celso Ramos (Latitude 27°18′S). It was a timely alert, preventing people from consuming this toxin. Recurrent blooms of *D. acuminata* and *D. caudata* are currently reported throughout the SC coast, especially in winter. In 2016, the bloom was particularly large, extending to the coastline of São Paulo. A very interesting phytoplankton succession was recorded after a few days, with the presence of *Noctiluca scintillans* and *Polykrikos polykrikoides*, as predators, owing to the high biomass of *Dinophysis* spp. This phenomenon has intensified and occurred at least every 2 years since 2007.

According to EPAGRI, SC's mariculture counts on the participation of 572 producers and generates a production of 20438 tons per year (oysters and mussels). This history of research and monitoring of HABs in SC showed a very important evolution in parallel with the growth of shellfish production. As also pointed out in classical studies (Hallegraeff 1993; Wells et al. 2015), an apparent increase in the occurrence of HABs was detected. This increase may be related to the increase in aquaculture operations that can act as "bioassay systems" for harmful algae, making previously unknown problem organisms detectable. Such increase could also be caused by anthropogenic eutrophication whereby coastal nutrient enrichment from wastewater stimulates the growth of some harmful species (Hallegraeff et al. 1995). Both possibilities are feasible in the case of the SC coast where mariculture has increased, as well as pollution, as a consequence of the high population growth rate in the region, which is one of the largest in Brazil. It is certain that winter is the period of high dinoflagellate incidence, which is clearly related to the influence of cold water masses that come from the south, carrying dinoflagellate-rich populations. The diversity and heterogeneity of microenvironments on the SC coast, in association with increased nutrients, can result in the greater proliferation of these algae when compared to the southernmost regions (RS state) or northernmost regions (PR and SP states). In other words, southern water masses act as inocula, while local conditions favor the development of some harmful microalgae species.

Regarding *Pseudo-nitzschia* spp., the occurrence of the potentially toxic species *P. calliantha* and *P. multiseries* has been confirmed on the SC coast. However, the production of domoic acid was first verified in Brazilian waters in 2009, and it caused the closing of two shellfish farms for 25 days in the region of Penha (Fernandes and Brandini 2010). Some authors have verified that *P. calliantha* and *P. multiseries* present higher growth rates and increase in domoic acid production in response to high concentrations of ammonium (Quijano-Scheggia et al. 2008; Ljubesic et al. 2011). Since ammonium is a nitrogenous nutrient often associated with organic pollution, it is possible that the large population increase on the SC coast, combined with insufficient wastewater treatment, could have contributed to the increased occurrence of *Pseudo-nitzschia* spp. blooms, as has been recorded in estuaries and bays of Santa Catarina Island (Rörig et al. in prep.).

The epibenthic diatoms *Amphitetras antediluviana* and *Biddulphia biddulphiana*, which occur in association with large masses of invasive bryozoans on the beach of Balneário Camboriú (Fig. 3d), were reported to cause an important non-toxic bloom, albeit still resulting in aesthetic and economic damage (Rörig et al. 2017b). These two filamentous species grow as epibionts on bryozoan masses, which are deposited on the beach after increased wave energy. Most deposited biomass can be attributed to bryozoans, but the relative importance of diatoms increases in winter and spring. This is another effect related to intense urbanization in the absence of adequate waste management.

5 New Challenges and Advances: The Towed Oceanographic Vehicle (VOR)

The Towed Oceanographic Vehicle (VOR) (Fig. 3e–f) was developed by Faccin et al. (2014), as a modified version of the CPR (Continuous Plankton Recorder; www.sahfos.ac.uk), for use in fishing vessels operating along the southeastern and southern Brazilian coast. The VOR can obtain samples of the planktonic community at low cost in ships of opportunity, but it can also be implemented in areas of greater ecological importance and economic interest, such as fishing areas. The first cruises with the VOR were carried out in May and June of 2013, covering the southern Brazilian continental shelf off the states of SP, PR, SC, and RS in areas with depths between 50 and 100 m. The mesh analysis resulted in the identification of 75 phytoplankton taxa. The main differences were recorded between transects off SC state and RS state, with high density of the cyanobacteria *Trichodesmium* spp. and high densities of *Thalassiosira* spp. and *Octotactis octonaria*, respectively (Tamanaha et al. 2016). The high density of diatoms and silicoflagellates was related to the higher concentration of silicates and other dissolved nutrients off RS state, especially during the winter, when the influence of the Río de la Plata and Patos Lagoon is more pronounced (Piola et al. 2000; Rigual-Hernandez et al. 2010).

Tamanaha et al. (2016) also reported that mesh size is a limitation for VOR samplings, essentially because pico- and nanoplankton were rarely collected, thus overestimating the presence of microphytoplankton, e.g., dinoflagellates, chain-forming diatoms, and filamentous cyanobacteria. Even so, some nanoplankton species were observed in high abundance, as in the case of the cyanobacteria *Johannesbaptistia* sp., which was very common in samples from transects of SC. VOR sampling efficiency was not evaluated, but CPR has been compared to traditional samplers in different studies, and it has proven to be robust (Batten et al. 2003). Tamanaha et al. (2016) concluded that VOR is a new and practical tool to help understand plankton trophic relationships and long-term community changes.

6 Conclusions and Suggestions

Historical data and recent research support the hypothesis that the coast of SC, Brazil, has features in common with the nearby regions to the north and south but also emerging and exclusive features with respect to the ecology of phytoplankton. The coastal transition is marked by the CSMG where coastal orientation and landscapes change. To the north of the CSMG, the coastline is more indented, with greater diversity of habitats, more creeks and inlets, and to the south, the coastline is more homogeneous, rectilinear, with fewer inlets. The relatively frequent occurrence of coastal upwelling in the CSMG also imposes a physical barrier such that the lower mean water temperature may interfere with the distribution, dispersion, and even survival of planktonic, benthic, and nektonic species. This set of environmental heterogeneities certainly influences the distribution, composition, and biomass of phytoplankton, especially when compared to areas to the north and to the south of SC.

This ecotone condition warrants more detailed studies in the region because in relatively small areas, several factors can affect pelagic ecology, which is very dynamic and variable both at seasonal and interannual scales. The importance of continuous and high-frequency monitoring to understand these processes is clear, as evidenced after the start of HAB monitoring when many previously unknown phenomena were detected and explained, leading to sound guidance for management activities and future studies.

Several topics can be suggested as pertinent for studies on phytoplankton on the coast of SC based on previous information, including the following:

- Verify the influence of nutrient enrichment by the pollution that flows to the coast, but also its probable toxic effect, and its potential to cause anoxia, owing to features of the regional watersheds with high level of contamination and toxic loads (Rörig 2005; Pereira-Filho and Rörig 2016).
- Carry out studies directed to areas of high fishing productivity in the region to understand trophic relationships.
- Evaluate the effects of highly acidic waters of the Araranguá River (latitude 28°53′S), which acts as drainage for an extensive coal mining region (Couceiro and Schettini 2010). The area can be considered a large-scale bioassay to assess the effects of acidification in the oceans.
- Understand the causes of the increased incidence of potentially harmful species in the winter, and improve the predictability of possible HABs for the management of mariculture.
- Evaluate the apparent increase in *Pseudo-nitzschia* spp. populations in the coastal zone, as an effect of ammonium excess from organic pollution.
- Determine the relationship between mullet populations (*Mugil* sp.), the main fishing resource on the SC coast, and surf diatom blooms, probably the main food source for this fish.
- Evaluate the possible disturbance of the surf diatom cycle at Navegantes Beach by the sediments dredged from the Itajaí-Açu River estuary.
- Verify the possible toxic effect of *Cylindrospermopsis raciborskii*, a saxitoxin producer (Miotto et al. 2017) from the Peri Lagoon (Santa Catarina Island) on shellfish from the coastal region where its waters flow.
- Understand the causes of *A. antediluviana* and *B. biddulphiana* blooms associated with bryozoans at Camboriú Beach in order to control the process, as well as anticipate or avoid its proliferation to other beaches.

References

Aidar E, Gaeta SA, Gianesella-Galvão SMF, Kutner MB, Teixeira C (1993) Ecossistema costeiro subtropical: nutrientes dissolvidos, fitoplâncton e clorofila-a e suas relações com as condições oceanográficas na região de Ubatuba, SP. Publ Esp Inst Oceanogr 10:9–43

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G (2013) Köppen's climate classification map for Brazil. Meteor Zeitschrift 22(6):711–728

Araujo N, Souza-Mosimann RM, Fernandes LF (1989) Contribuição ao estudo das diatomáceas (Bacillariophyceae) da Foz do Rio Araranguá – SC – Brasil. Ínsula 19:305–334

Batten SD, Flinkman R, Clark J, Hays G, John E, John AWG, Jonas T, Lindley JA, Stevens DP, Walne A (2003) CPR sampling: the technical background, materials and methods, consistency and comparability. Prog Oceanogr 58:193–215

Brandini FP (1988) Hydrography, phytoplankton biomass and photosynthesis in shelf and oceanic waters off Southeastern Brazil during autumn (May/June 1983). Braz J Oceanogr 36:63–72

Brandini FP (1990a) Producão primária e características fotossintéticas do fitoplâncton na Região Sueste do Brasil. Braz J Oceanogr 38:147–159

Brandini FP (1990b) Hydrography and characteristics of the phytoplankton in shelf and oceanic waters off Southeastern Brazil during winter (July/August 1982) and summer (February/March 1984). Hydrobiologia 196:111–148

Becker EC (2014) Comunidade planctônica da plataforma continental de Santa Catarina (26-29°S):distribuição e estrutura de tamanho de fitoplâncton e zooplâncton, com ênfase em copépodes. Dissertação deMestrado, Universidade Federal de Santa Catarina

Campos EJ, Goncalves J, Ikeda Y (1995) Water mass characteristics and geostrophic circulation in the South Brazil Bight: summer of 1991. J Geophys Res 100:18537–18550

Cardoso LS, Baptista LRM, Jebram DHA (1994) Dinoflagelados da ilha do Arvoredo e da praia de Ponta das Canas-Santa Catarina, Brasil (Setembro de 1991 a Fevereiro de 1992): condições hidrológicas e lista de Espécies. Iheringia 45:143–155

Carpenter EJ, Price CC (1977) Nitrogen fixation, distribution, and production of Oscillatoria (Trichodesmium) spp. in the western Sargasso and Caribbean seas. Limnol Oceanogr 22:60–72

Carvalho JLB, Schettini CAF, Ribas TM (1998) Estrutura termohalina do litoral centro-norte catarinense. Notas Técnicas da FACIMAR 2:181–197

Castro BM, Miranda LB (1998) Physical oceanography of Western Atlantic continental shelf located between 4°N and 34°S. In: Robinson AR, Brink KH (eds) The sea, vol 2. Wiley, New York, pp 209–251

CIDASC - Companhia Integrada de Desenvolvimento Agrícola de Santa Catarina (2017) Florianópolis. Santa Catarina, Brazil. http://www.cidasc.sc.gov.br/. Accessed 22 Sept 2017

Ciotti AM, Odebrecht C, Fillmann G, Moller O Jr (1995) Freshwater outflow and Subtropical Convergence influence on phytoplankton biomass on the southern Brazilian continental shelf. Cont Shelf Res 15:1737–1756

Couceiro MAA, Schettini CAF (2010) Estudo da dinâmica dos sedimentos em suspensão do estuário do rio Araranguá (SC): possíveis efeitos da drenagem ácida da atividade de mineração de carvão. Geociências 29:251–266

Detoni AMS, Costa LF, Abrão LP, Sarkis JY (2016) Toxic *Trichodesmium* bloom occurrence in the southwestern South Atlantic Ocean. Toxicon 110:51–55

Faccin J, Cunha DMC, Barddal R, Resgalla C Jr (2014) Development of an oceanographic towing vehicle adapted for fishing craft: prototype and protocol for use. Methods Oceanogr 9:61–74

Fernandes LF, Brandini FP (2010) The potentially toxic diatom *Pseudo-nitzschia* H. Peragallo in the Paraná and Santa Catarina States, Southern Brazil. Iheringia 65:47–62

Firpo MAF, Sansigolo CA, Assis SV (2012) Climatologia e variabilidade sazonal do número de ondas de calor e de frio no Rio Grande do Sul associadas ao ENOS. Rev Bras Meteorologia 27(1):95–106

Fay P (1992) Oxygen relations of nitrogen fixation in cyanobacteria. Microbiol Rev. 56(2): 340–373

Gaeta AS, Brandini FP (2006) Produção primária do fitoplâncton na região entre o Cabo de São Tomé (RJ) e o Chuí (RS). In: Rossi-Wongtschowski CL, Madureira LS (eds) O Ambiente Oceanográfico da Plataforma Continental e do Talude na Região Sudeste-Sul do Brasil. EDUSP, São Paulo, pp 219–264

Gianesella-Galvão SMF (2000) Variabilidade da camada de clorofila máxima na região de quebra de plataforma continental sudeste brasileira. Dissertation, Instituto Oceanográfico da Universidade de São Paulo

Grimm AM (2009a) Clima da Região Sul do Brasil. In: Cavalcanti IFA et al. (orgs) Tempo e Clima no Brasil. Oficina de Textos, São Paulo

Grimm AM (2009b) Variabilidade Interanual do Clima no Brasil. In: Cavalcanti IFA et al.(orgs) Tempo e Clima no Brasil. Oficina de Textos, São Paulo

Guimarães SCP, Rörig LR (1997) Microrganismos associados a florações de *Trichodesmium hildebrandtii* na costa de Santa Catarina - Brasil. Notas Técnicas da FACIMAR 1:43–47

Hallegraeff GM (1993) A review of harmful algal blooms and their apparent global increase. Phycologia 32(2):79–99

Hallegraeff GM, Anderson DM, Cembella AD (1995) Manual on harmful marine microalgae. UNESCO, Paris

Islabão CA, Odebrecht C (2011) Dinoflagelados (Peridiniales, Prorocentrales) do microplâncton na plataforma continental e talude do extremo sul do Brasil (inverno 2005, verão 2007). Biota Neotrop 11(3):153–166

Ito RG, Garcia CAE, Tavano VM (2016) Net sea-air CO2 fluxes and modelled pCO2 in the southwestern subtropical Atlantic continental shelf during spring 2010 and summer 2011. Cont Shel Res 119:68–84

Kaczmarska I, Mather L, Luddington IA, Muise F, Ehrman JM (2014) Cryptic diversity in a cosmopolitan diatom known as Asterionellopsis glacialis (Fragilariaceae): implications for ecology, biogeography, and taxonomy. Am J Bot 101(2):267–286

Ljubesic Z, Bosak S, Vilicic D et al (2011) Ecology and taxonomy of potentially toxic *Pseudo-nitzschia* species in Lim Bay (north-eastern Adriatic Sea). Harmful Algae 10:713–722

Miotto MC, Tamanaha MS (2012) Ocorrência de dinoflagelados tecados potencialmente tóxicos em cultivo de moluscos situados no município de Penha, SC. Braz J Aquat Sci Technol 16:53–67

Miotto MC, Costa LF, Bretano DM, Nader C et al (2017) Ecophysiological characterization and toxin profile of two strains of *Cylindrospermopsis raciborskii* isolated from a subtropical lagoon in Southern Brazil. Hydrobiologia 802(1):97–113

Monteiro MA (2001) Caracterização climática do estado de Santa Catarina: uma abordagem dos principais sistemas atmosféricos que atuam durante o ano. Geosul 16(31):69–78

Odebrecht C (1988) Variações espaciais e temporais do plâncton (fitoplâncton, protozooplâncton e metazooplâncton) na Lagoa da Conceição, Ilha de Santa Catarina, Brasil. Atlântica 10:21–40

Odebrecht C, Bergesch M, Rörig LR et al (2010) Phytoplankton interannual variability at Cassino Beach, Southern Brazil (1992:2007), with emphasis on the surf zone diatom *Asterionellopsis glacialis*. Estuar Coasts 33:570–583

Odebrecht C, Du preez DR, Abreu PCOV et al (2014) Surf zone diatoms: a review of the drivers, patterns and role in sandy beaches food chains. Estuar Coast Shelf Sci 150:24–35

Pandolfo C, Braga HJ, Silva VP Jr et al (2002) Atlas climatológico do Estado de Santa Catarina. Epagri, Florianópolis. CD-ROM

Pellens IC (1997) Dinâmica de Nutrientes Inorgânicos no Estuário do Rio Itajaí-Açu / SC. Trabalho de Conclusão de Curso, Universidade do Vale do Itajaí

Pereira-Filho J, Rörig LR (2016) Balanço de massa para nutrientes inorgânicos (N e P) no estuário do rio Itajaí-Açu, SC. Rev Bras de Recur Hídr 21:168–187

Piola A, Campos ED, Moller OO Jr et al (2000) Subtropical shelf front off eastern South America. J Geophys Res 105:6565–6578

Proença LAO, Rörig LR (1995) Mussel production and toxic algal blooms in Santa Catarina state, southern Brazil. Harmful Algae News 12/13:5

Proença LAO, Schmit F, Costa TF et al (1998) Evidences of diarrhetic shellfish poisoning in Santa Catarina - Brazil. Ciência e Cultura (SBPC) 50(6):458–462

Proença LAO, Tamanaha MS, Souza NP (2001) The toxic dinoflagellate *Gymnodinium catenatum* in Southern Brazilian Waters: occurrence, pigments and toxins. Atlântica 3:59–65

Proença LAO, Tamanaha MS, Fonseca RS (2009) Screening the toxicity and toxin content of a bloom of the cyanobacterium *Trichodesmium erythraeum* (Ehrenberg) in northeast Brazil. J Venomous Anim Toxins Incl Trop Dis. 15:204–215

Quijano-Scheggia S, Garcés E, Sampedro N et al (2008) Identification and characterisation of the dominant Pseudo-nitzschia species (Bacillariophyceae) along the NE Spanish coast (Catalonia, NW Mediterranean). Sci Mar b 72:343–359

Resgalla Jr C (2009) Zooplâncton do estuário do rio Itajaí-açu e zona costeira adjacente. In: Branco JOB, Lunardon-Branco MJ, Bellotto VR (Org). Estuário do Rio Itajaí-açu, Santa Catarina: caracterização ambiental e alterações antrópicas. 1ed. Editora Univali, Itajaí SC (1): 171–179

Resgalla Jr C, Carvalho JLB, Pereira-Filho J et al. (2004) Migração vertical e taxas fisiológicas de *Thalia democratica* (Salpidae: Thaliacea) na Reserva Marinha do Arvoredo, Santa Catarina. Notas Técnicas da FACIMAR (8): 45–54

Resgalla C Jr, Souza VGC, Klein AHF (2005) The occurrence of jellyfish stings on the Santa Catarina coast, southern Brazil. Ver Bras Oceanogr 53(3/4):183–186

Rezende KRV, Brandini FP (1987) Variacão sazonal do fitoplâncton na zona de arrebentação na Praia de Pontal do Sul (Pontal do Paraná, PR). Nerítica 11:12–19

Richardson K (1987) Primary production: guidelines for measurement by 14C incorporation. The Danish Institute for Fisheries and Marine Research, Charlottenlund. 21p

Rigual-Hernandez AS, Barcena MA, Sierro FJ et al (2010) Seasonal to inter-annual variability and geographic distribution of the silicoflagellate fluxes in the Western Mediterranean. Mar Micropal 77:46–57

Rodrigues MLG, Franco D, Sugahara S (2004) Climatologia de frentes frias no litoral de Santa Catarina. Rev Bras Geof 22(2):135–151

Rörig LR (2005) Usos múltiplos e qualidade das águas da bacia do baixo Itajaí-Açu-SC: elementos para um gerenciamento integrado. Tese de Doutorado, Universidade Federal de São Carlos

Rörig LR et al (1997) Variação sazonal do fitoplâncton na área da Reserva Biológica Marinha do Arvoredo (Santa Catarina - Brasil). In: Resumos do VII COLACMAR - Congresso Latino-Americano de Ciências del Mar, Universidade de São Paulo, 1997

Rörig LR, Yunes, JS, Kuroshima KN et al. (1998a). Studies on the ecology and toxicity of *Trichodesmium* spp blooms in Southern Brazilian Coast. In: Harmful Algae. Ed. Pontevedra, Paris: Xunta de Galicia, IOC – UNESCO, pp 22–25

Rörig LR, Guimarães SCP, Lugli DO et al (1998b) Monitorização de microalgas planctônicas potencialmente tóxicas na área de maricultura da Enseada de Armação do Itapocorói - Penha - SC. Notas Técnicas da FACIMAR 2:71–79

Rörig LR, Resgalla C Jr, Schettini CAF (2003) Estrutura da assembleia planctônica através do estuário e da pluma do Rio Itajaí-açu. Rev Est Amb 5(1):76–94

Rörig LR, Honorato M, Itokazu AG et al. (2017a) Ecophysiological and biochemical variation of the surf zone diatom Asterionellopsis glacialis sensu lato from Santa Catarina, Southern Brazil. Braz J Oceanogr. 65(4):702–715

Rörig LR, Ottonelli M, Itokazu, AG et al. (2017b) Blooms of bryozoans and epibenthic diatoms in an urbanized sandy beach (Balneário Camboriú - SC - Brazil): dynamics, possible causes and biomass characterization. Braz J Oceanogr. 65(4):685–701

Satô S, Paranaguá MN, Eskinazi E (1963) On the mechanism of red tide of *Trichodesmium* in Recife north eastern Brazil, with some considerations of the relation to the human disease Tamandaré Fever. Trab Inst Oceanogr (Univ Recife) 5(6):7–49

Schettini CAF, Kuroshima KN, Pereira-Filho J et al (1998) Oceanographic and ecological aspects on the Itajaí-açu river plume during a high discharge period. Anais Acad Bras de Ciênc 70(2):335–351

Schettini CAF, Resgalla C Jr, Pereira-Filho J et al (2005) Variabilidade temporal das características oceanográficas e ecológicas da região de influência fluvial do rio Itajaí-Açu. Braz J Aquat Sci Tech 9(2):93–102

Silva LM, Matthiensen A, Yunes JS (2008) Florações de *Trichodesmium* na Costa Brasileira. In: Baptista Neto JA, Kersanach MW, Patchineelam SM (Org.). Poluição Marinha. 1ed. Intersciencia, Rio de Janeiro, 03–19 p

Siqueira A, Kolm HE, Brandini FP (2006) Offshore distribution patterns of the cyanobacterium *Trichodesmium erythraeum* Ehrenberg and associated phyto- and bacterioplankton in the southern Atlantic coast (Paraná, Brazil). Braz Arch Biol Technol 49:323–337

Talbot MM, Bate GC (1988) The use of false buoyancies by the surf diatom *Anaulus birostratus* in the formation and decay of cell patches. Estuar Coast Shelf Sci 26:155–167

Talbot MM, Bate GC, Campbell EE (1990) A review of the ecology of surf zone diatoms, with special reference to *Anaulus australis*. Oceanogr Mar Biol Annu Rev 28:155–175

Tamanaha MS, Proença LAO, Schramm MA et al. (2008) Gênero *Pseudo-nitzschia* H. Peragallo 1899 no parque de maricultura do município de Penha, SC: taxonomia e prodição de toxina amnésica durante uma floração. In: Resumos do XII Congresso Brasileiro de Ficologia, 2008, Brasilia

Tamanaha MS, Cunha DMC, Resgalla C Jr (2016) The first continuous plankton sampling by VOR (Towed Oceanographic Vehicle) in southeastern and southern Brazil waters. Lat Am J Aquat Res 44(5):935–946

Tedesco EC, Ribeiro SMMS, Pompeu M, Gaeta AS, Cavalcante KP (2017) Low-latitude accumulation of the surf-zone diatoms *Anaulus australis* Drebes & Schulz and *Asterionellopsis glacialis* (Castracane) Round species complex in the eastern coast of Brazil. Braz J Oceanogr 65(2):324–331

Wells ML, Trainer VL, Smayda TJ, Karlson BSO, Trick CG, Kudela RM, Ishikawa A, Bernard S, Wulff A, Anderson DM (2015) Harmful algal blooms and climate change: learning from the past and present to forecast the future. Harmful Algae 49:68–93