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Changes in biomass and botanical composition of beach-cast seaweeds in a disturbed coastal area from Argentine Patagonia

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Abstract

Trends in wrack composition and biomass, and its relationship with the anthropogenic impact were studied along a coastal area in Nuevo Gulf (south Patagonia) in front of Puerto Madryn city. Beach-cast macroalgae composition was sampled from 1992 to 1999 in the Puerto Madryn beaches and in several other nearby beaches in 1993, 1996 and 1998. Historical information was based on local knowledge and observations reported by marine biologists who worked in the area. The botanical composition of the beach-cast macroalgae in Puerto Madryn indicates a succession in the dominance from *Codium* spp. to *Ulva* spp. during the 1990s and from *Ulva* to *Undaria pinnatifida* since 1998, accompanied by a significant decrease in biomass of *Gracilaria gracilis* and *Macrocystis pyrifera*. The increase of the opportunist species such as *Ulva* may be supported by the continuous delivery of waste waters into the Nuevo Gulf while the dominance of *U. pinnatifida* may be associated with port activities. During the sampling period the highest wrack biomass values were recorded in spring and summer. The beach-cast seaweed biomass harvested by the municipality of Puerto Madryn during beach cleaning operation, ranged between 2500 and 12000 t year^{-1} (˜ 200 and 960 t dry weight). Wrack harvesting produces an environmental impact by removing sand from the beach and affecting coastal communities. Composting of wrack is proposed as one of the environmental alternatives to land disposal.

Introduction

Increases in algal biomass and changes in the structure of macroalgal assemblages are usually considered symptoms of eutrophication resulting from industrial, domestic or agricultural wastes (Morand et al. 1990; Morand and Briand 1996). However, information about long-term trends in sublitoral seaweed assemblages is scarce.

The relationship between detached macrophytes and living attached plants has not been clearly established. This is mainly because the interactions between winds and nearshore currents, and their influence on transport of drifting biomass to and from the beach, are not well understood (Kirkman and Kendrick 1997). However, certain characteristics of wrack could be used as indicators of changes of nearby macroalgal communities.

The Nuevo Gulf (42°45′ S; 64°55′ W) is an area where considerable algal biomass is produced yearly; part of this biomass is detached and cast on the beach during severe windstorms with prevailing northern winds (pers. obs.). These detached seaweeds particularly affect the beach of Puerto Madryn, a town of 60,000 inhabitants. Puerto Madryn probably has an environmental impact on the marine ecosystem through the discharges of poorly treated waste water (residential and industrial) as well as by the activities related to the local harbor (i.e. fouling, ballast waters). However, local inhabitants commonly assert that beach cast seaweed has increased over time due to continuous wastewater discharge.

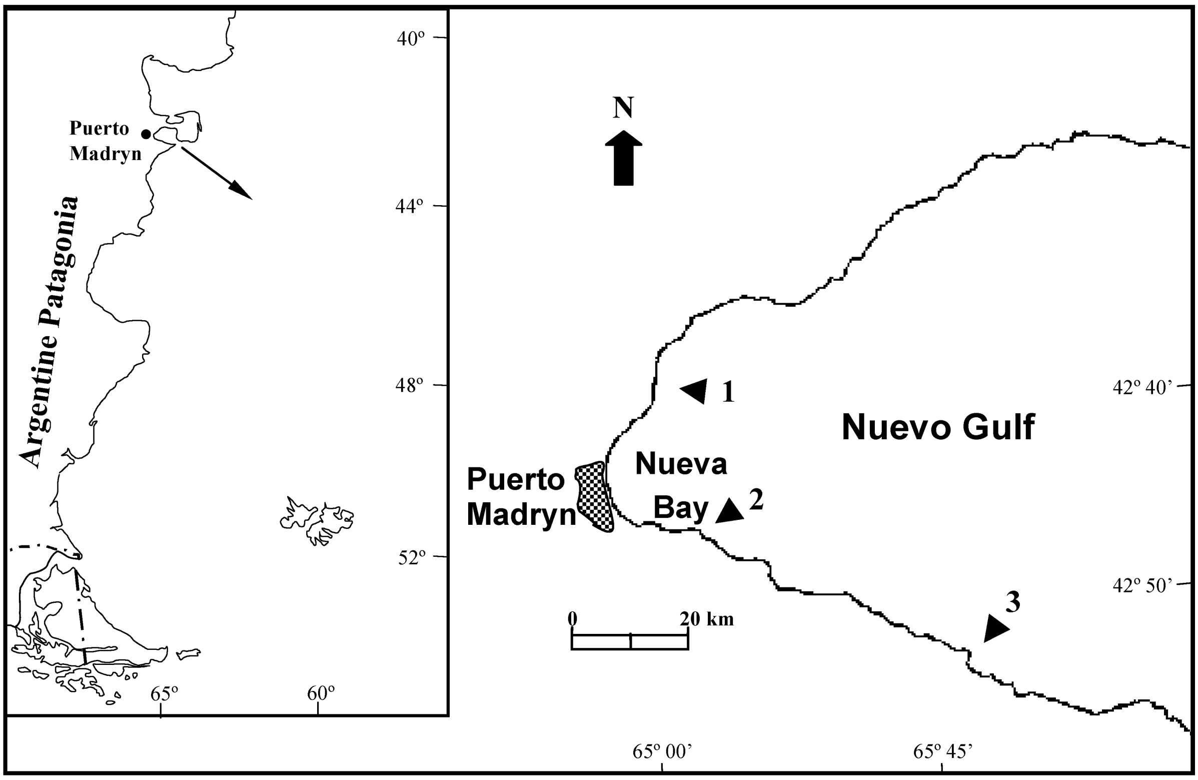

Figure 1. Study area. 1, El Doradillo; 2, Punta Este; 3, Punta Conscripto.

The algal biomass cast ashore interferes with recreational uses of the beaches and therefore must be periodically collected and disposed off. The harvesting of wrack helps reduce inorganic nutrients and organic matter from eutrophicated coastal waters (Schramm 1991). However, this strategy and the final disposition of this biomass may only transfer the original organic matter. This could be partially remedied using the beached algae as raw material for the production of compost, biogas (Morand et al. 1990; Schramm 1991; Mazé et al. 1993; Eyras et al. 1998), compound feedstuffs, green manure, poultry fodder (Briand 1991) or industrial products such as agar or alginate (Kirkman and Kendrick 1997).

In order to establish sound management and utilisation strategies, qualitative analyses and quantification of the wrack is necessary. However, few studies have been focused in this area (ZoBell 1959; Câmara Neto et al. 1981; Escofet and Burgueño 1993).

The aim of this study was to document the changes in botanical composition and biomass of the seaweed wrack in Puerto Madryn beach over time, and analyse their possible connection with environmental perturbations. We also propose utilisation of the wrack and predict the likely effects of the algal harvesting on the coastal ecosystem.

Materials and methods

Study area

A 4.5-km long of section shore located in front of Puerto Madryn city (42°45′ S; 64°55′ W) was surveyed between 1992 and 1999. Samples were also collected from three non-urban sites, ″El Doradillo″, ″Punta Conscriptos″ and ″Punta Este″, considered to be free of anthropic perturbation (Figure 1). Different methodologies were adopted according to the different objectives proposed in the present study.

Beach-cast macro-algae composition (seaweed inventory)

The floristic composition was determined in randomly collected samples from the most significant beach-cast seaweeds deposited in the Puerto Madryn beach from 1992 to 1996, and in January 1998 and October 1999.

The relative abundance of the dominant taxa was determined by dry weight (oven dry at 60 °C to constant weight) in 500 g wet samples. The portion of the seaweed biomass classified as ″remains″ corresponds to fragmented seaweeds that could not be identified due to their small size, advanced decomposition, or being seasonal species that were not abundant.

Complementary sampling of beach-cast seaweeds was carried out in nearby beaches (El Doradillo in 1993 and 1998, Punta Este in 1993, and Punta Conscriptos in June 1996, Figure 1). Given the lack of systematic studies of beach-cast seaweeds in Puerto Madryn, information from local inhabitants was the main source of information on historical changes of beach-wracks. Older citizens were interviewed who provided historical photographs and personal information. Personal observations reported by marine biologists who worked in the area were also considered.

Beach-cast seaweed biomass

Over the period 1992–1994, the biomass of the most significant seaweed wracks was monthly estimated by measuring the volume and volume:weight ratio of samples of the different seaweed deposits. The 4.5 km long beach section in front of Puerto Madryn was divided into 90 sections of 50 m each and the volume of seaweed was estimated by first classifying seaweed deposits into three categories:

Ridges are long deposits of seaweeds that run parallel to the shoreline. The total volume of seaweeds present in each section was estimated by determining the volume of a 0.50 m fragment in a randomly selected point along the ridge and measuring the length of the ridge in the section. Mounds or piles of seaweeds were counted in each section and their volume was determined by measuring height and major and minor diameters. In both, ridges and mounds, the bulk density (wet and dry weigh to volume ratio) was determined in 2-L samples taken with a cylinder, weighed before and after oven-drying to 105 °C.

For continuous cast seaweed cover the area occupied by the deposits was measured in each section. The volume:wet weigh ratio of the seaweed wrack was determined in 10 randomly selected 1 m^2 quadrats. The water content of these samples was determined by oven drying 1 kg samples to 105 °C.

To avoid tidal disruption of the wrack, biomass estimation was done considering only freshly cast ashore seaweeds. Therefore, our records are likely to underestimate the biomass of the wrack.

Table 1. Macroalgae recorded throughout the studying period.

CHLOROPHYTA
Bryopsis sp.
Chaetomorpha linum (Müller) Kützing
Cladophora sp.
Codium decorticatum (Woodward) Howe
Codium fragile (Sur.) Hariot
Codium vermilara (Olivi) Delle Chiaje
Enteromorpha spp.
Ulva spp.
PHAEOPHYTA
Cladostephus sp.
Colpomenia sinuosa (Roth.) Derbès et Solier
Cutleria multifida (Turner) Greville
Dictyota dichotoma (Hudson) Lamouroux
Ectocarpus sp.
Haloglossum compressum (Griffiths) Hamel
Halopteris sp.
Macrocystis pyrifera (Linnaeus) C. Agardh
Eudesme virescens (Carmichael) J. Agardh
Punctaria sp.
Scytosiphon lomentaria (Lyngbie) Link
Sphacelaria sp.
Undaria pinnatifida (Harvey) Suringar
RHODOPHYTA
Anotrichium furcellatum (J. Agardh) Baldock
Antithamnion sp.
Aphanocladia robusta Pujals
Callithamnion sp.
Ceramium rubrum (Hudson) C. Agardh
Ceramium sp.
crustose Corallinaceae
Gracilaria gracilis (Stackhouse) Steentoft, L.Irvine et Farnham
Heterosiphonia merenia Falkenberg
Hymenena laciniata (Hooker et Harvey) Kylin
Lomentaria clavellosa (Turner) Gaillon
Medeiothamnion flaccidum (Hooker et Harvey) Brauner
Phycodrys sp.
Polysiphonia argentinica Taylor
Porphyra aff. *leucosticta* Thuret
Porphyra columbina Montagne
unidentified Rhabdoniaceae[1]
Rhodymenia or *Epymenia*[2]
Streblocladia corymbifera (C. Agardh) Kützing
Tube-dwelling diatoms

[1]Material under study
[2]Sterile plants

During spring and summer the municipality of Puerto Madryn mechanically removed seaweed wracks from the beach and transported them by truck to the land. Therefore, we adopted a different sampling schedule for these seasons. The biomass of seaweed harvested in this way from 1992 to 1999 was estimated by recording the number of loads transported by municipal trucks during each cleaning operation, estimating that each truck carried about 5 wet tons of seaweeds that included about 50% of sand in dry weight.

The spatial distribution of seaweed wrack was calculated from the total amount of macroalgae deposited in each beach section throughout the period June, 1992–September, 1994.

To assess the redistribution of a given seaweed cast, several seaweed samples were enclosed into 15 × 15 cm meshed-red bags (n = 35), tagged and left back in the wrack at northern sections. Twenty-four hours later several bags were recovered and their new position registered.

Results

Beach-cast seaweed botanical composition

Of 44 taxa recorded throughout the study period, 8 were green, 13 brown, and 19 were red algae among the cast-ashore seaweeds in Puerto Madryn (Table 1). Some of them were present in all the wracks sampled throughout the whole sampling period while others exhibited seasonal frequencies.

Historical information about seaweed wrack from 1930 to 1950, recovered from old photographs and personal interviews, indicate the dominance of *Codium* spp. and significant deposits of *Macrocystis pyrifera* and *Gracilaria gracilis*. According to the information provided by biologists who worked in the area and older citizens this situation remained unchanged from the 1960's to the 1980's (Table 2).

In the sampling period 1992–1996, *Ulva* spp. and *Dictyota dichotoma* were the dominants in the seaweed wrack, accounting for 35% and 28% of the total biomass, respectively. In this period, species of *Codium* represented 7% of the seaweed wrack biomass (Figure 2a). In contrast, during 1998 and 1999, *Undaria pinnatifida*, an annual species, became dominant in the seaweed wrack of Puerto Madryn. This species accounted for 14% of the total biomass in the spring samples (October 1999) (Figure 2b) and 52% in the summer samples (January 1998) (Figure 2c) . Senescence of *U. pinnatifida* during the summer months resulted in large wrack biomass.

In the samples collected in ″Punta Conscriptos″ (Figure 2d), ″El Doradillo″ and ″Punta Este″ in June 1996, species of *Codium* were dominant, accounting for 99% of the wrack-biomass.

Table 2. Historical review of drift seaweeds on Puerto Madryn beach.

Period	Prevailing seaweeds	Information source	References
1930	*Codium* spp. *Gracilaria gracilis* *Macrocystis pyrifera*	Photo and personal communications: Biologists and old settlers	
1950	*Codium* spp. *Gracilaria gracilis* *Macrocystis pyrifera*	Photo and personal communications: Biologists and old settlers	Boraso de Zaixso and Kreibohm de Paternoster, 1984
1977	*Codium* (prevailing) Very few: *Ulva* *Polysiphonia* *Gracilaria* *Macrocystis* *Leathesia*[1]	Invertebrate samples on drift seaweeds	Escofet, pers. com.
1985	*Codium vermilara*		Lobban et al. (1985)
1992–96	*Ulva* spp. *Dictyota dichotoma*		This study
1998–99	*Undaria pinnatifida* *Ulva* spp.		This study

[1] may be a misidentification of *Colpomenia*

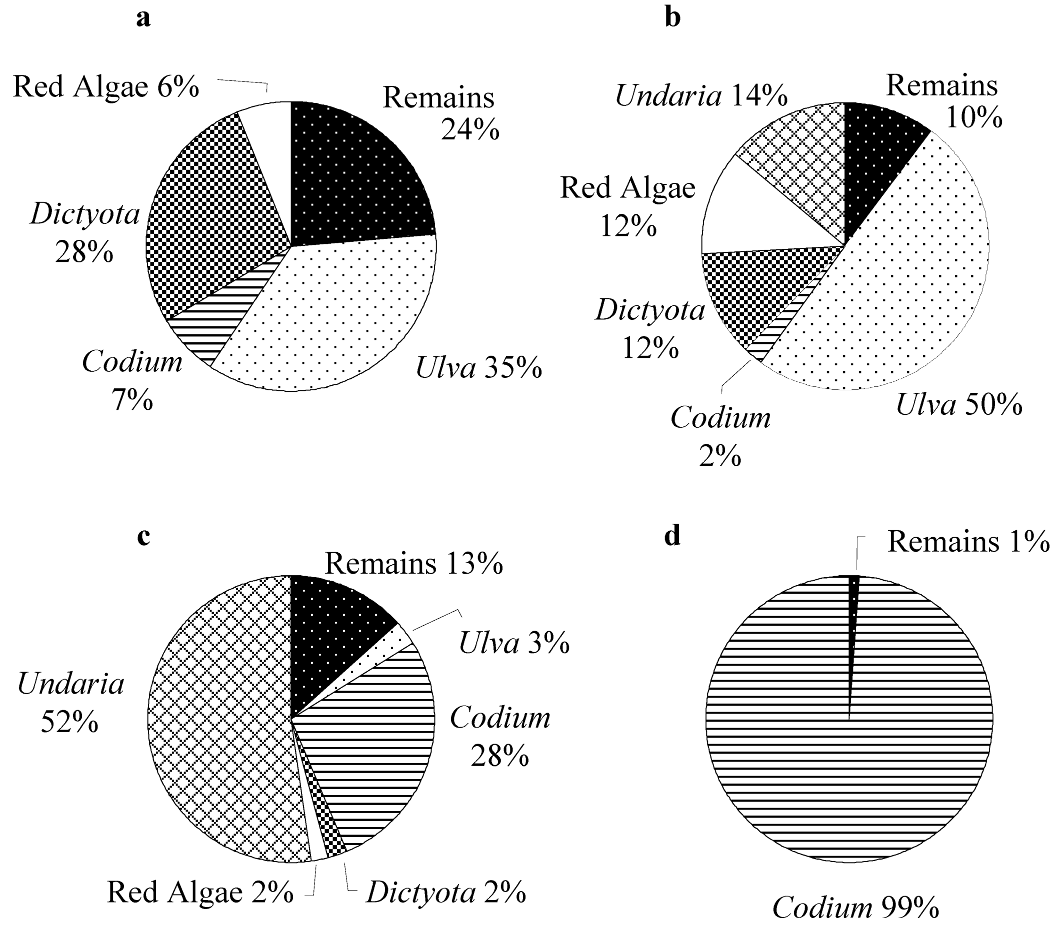

Figure 2. Floristic composition of the wracks at Puerto Madryn (a–c) and a nearby beach (d) a, 1992–96; b, October 1999; c, January 1998; d: Punta Conscripto 1996.

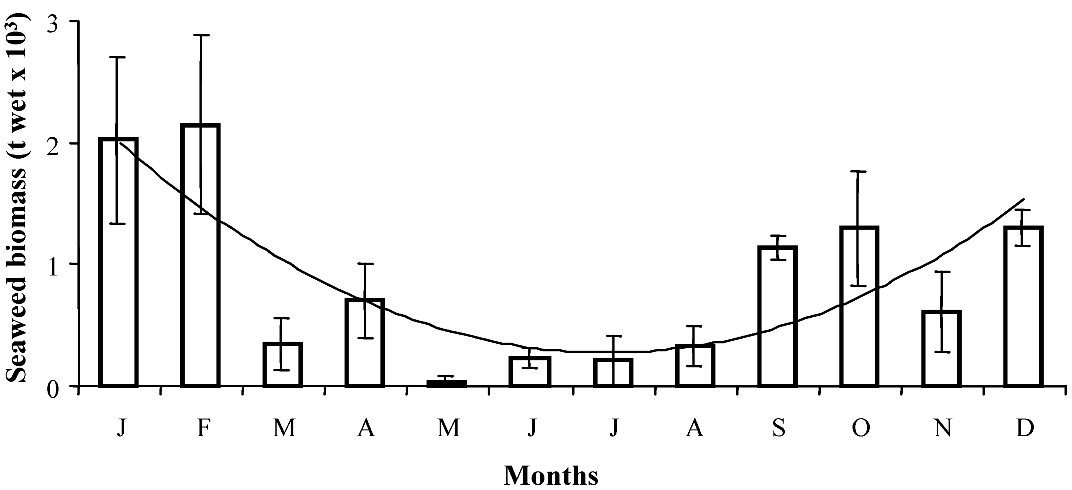

Figure 3. Average monthly variation in seaweed wrack biomass along the studying period. (Error bars show S.E.).

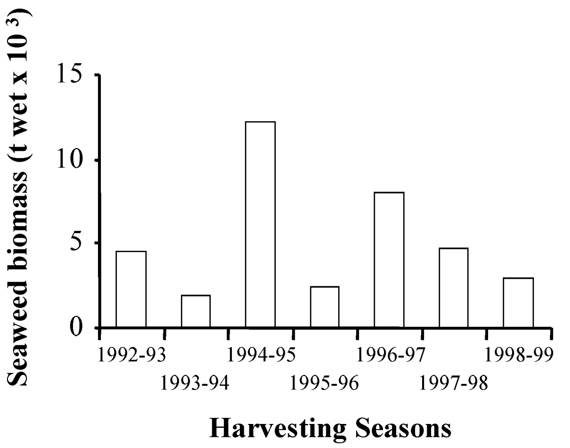

Figure 4. Biomass of drift seaweeds harvested by the Municipality of Puerto Madryn during spring and summer.

Beach-cast seaweed biomass

During the period 1992–1994, seaweed wrack was measured every month, with the highest biomass recorded in spring and summer (Figure 3). The beach-cast seaweed biomass harvested by the municipality of Puerto Madryn presented a great variation among years and ranged between 2500 and 12000 t year^{-1} (wet weight), equivalent to approximately 200 and 960 t (dry weight) (Figure 4).

The beach-cast seaweeds along the Puerto Madryn beach were not homogeneously distributed; the highest biomasses being accumulated in the southern extreme of the beach (Figure 5). Of the 35 tagged bags left in the northern extreme, only seven were recovered within the next 24 h. These bags had been moved between 1000 and 1600 m to the south.

Discussion

Information obtained from old photographs, interviews of inhabitants of Puerto Madryn, Halperin et al. (1973), Escofet (pers. comm.) and Lobban et al. (1985) indicates the genus *Codium* was dominant in the seaweed wrack between 1930 and 1985. *Ulva*, *Polysiphonia*, *Macrocystis* and *Leathesia* accompanied those large wracks of *Codium* spp. However, it cannot be ruled that '*Leathesia*' in the field notes of Escofet maybe a misidentification of *Colpomenia*.

Ulva spp. were an important component of the seaweed wrack at Puerto Madryn during 1992–1996 while *Codium vermilara* was the dominant species in nearby beaches not affected by urban effluent discharges. Since 1998 the dominance has changed from *Ulva* spp. to *Undaria pinnatifida*, particularly during spring and summer.

The few studies available about seaweeds from Nuevo Gulf (Olivier et al. 1966; Halperin et al. 1973; Barrales and Lobban 1975) do not allow for the characterisation of the taxonomic structure of the subtidal algal beds and their relation with the drift seaweeds. However, the major changes in the botanical composition of the beach-cast macroalgae of the Puerto Madryn beach reported here, provide evidence that there have been substantial shifts in the subtidal communities from which these wracks originate.

A succession in the dominance from *Codium* spp. to *Ulva* spp. took place first and more recently from *Ulva* spp. to *Undaria pinnatifida*. These changes in dominance could have been accompanied by a significant decrease of *Gracilaria gracilis* and *Macrocystis pyrifera* that disappeared from the wracks.

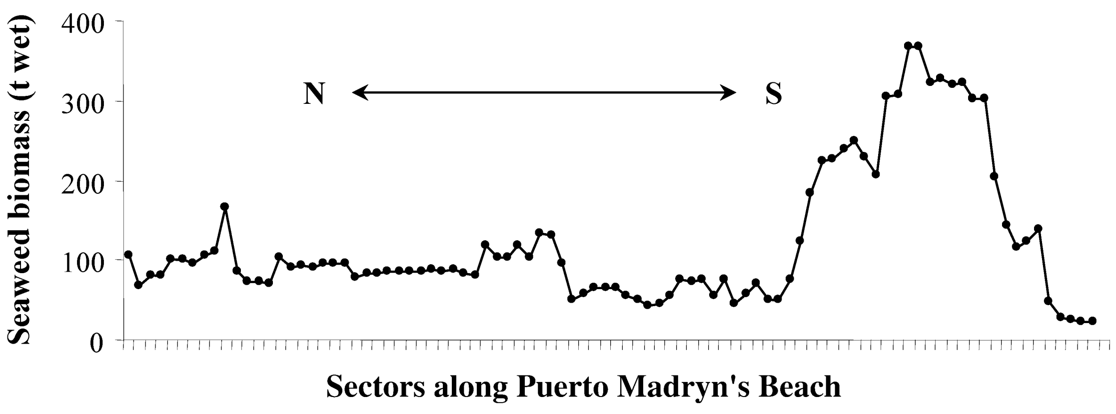

Figure 5. Spatial distribution of drift seaweed biomass along Puerto Madryn beach. Each point corresponds to each one of the 90 sectors sampled during the present study.

There are at least two factors that could explain the hypothesized changes in the composition of the subtidal communities: the introduction of invasive species and the increase of nutrient inputs. The invasion of the alien *U. pinnatifida* has been related with its ability to rapidly use dissolved inorganic N (Campbell 1999) and to port activities (Piriz and Casas 1994; Casas and Piriz 1996). A foreseeable result of this invasion is the loss of biodiversity in the benthic community, as has been demonstrated for other localities (Walker and Kendrick 1998). The second factor is related to the population boom of Puerto Madryn by the mid-1980s resulting in a steady increase in discharge of municipal and industrial wastewater to Nueva Bay. High nutrient concentrations may have caused the increase in *Ulva*, replacing *Codium* spp. as the dominant.

Orensanz (1986) suggested that the gradient in algal dominance in San José Gulf, near to Nuevo Gulf, (*Ulva* in the N-W to *Codium* in the S-E) was related to the gradient of biologically available nitrogen. The continuous delivery of dissolved inorganic N into the Nuevo Gulf may favour the increase in opportunist species such as *Ulva* (Diaz et al. 2002), as has been widely demonstrated for eutrophic coastal ecosystems (Waite and Mitchell 1972; Huvé et al. 1973). However, the biomass harvested during spring and summer, the seasons when the highest biomass were recorded, did not significantly change along 1992–98 as it was expected considering the steady increase of the waste water effluent discharged in Nueva Bay. The harvesting of the beach-cast seaweeds carried out by the municipality in order to keep the beach in good condition for the recreational activities, removed part of the nutrient added with the wastewater.

It has been shown that macroalgae can be used to remove waste nutrients from eutrophic waters. Schramm (1991) estimated that harvesting macroalgae, mainly *U. lactuca*, removed 56% and 39% of the total nitrogen and phosphorous discharged into a Danish fjord during 1985. Approximate figures for the dissolved nitrogen and phosphorous input to Nueva Bay with the effluent discharge during the year 1995 were 122 and 15 t, respectively (Estéves et al. 1997). Average N and P concentrations in the wrack were 17.7 and 1.04 g kg^{-1}, respectively (Eyras unpublished results). Thus, the amount of nitrogen and phosphorus removed with the 960 dry tons of harvested drift in 1994–95 season is estimated to be 17 and 1 t respectively. These figures represent 14 and 6.7% of the total input.

To avoid further eutrophication, the target would be the suppression of the input of nutrients from land, a measure that has been recently implemented by the wastewater treatment plant in Puerto Madryn.

The high cost of the seaweed harvesting could in part be sustained through a beneficial use of the seaweed wrack. One promising use is its utilisation to prepare compost, a marketable and environmentally sound product (Morand et al. 1991; Schramm 1991; Cuomo et al. 1995; Eyras and Rostagno 1996; Eyras et al. 1998). In other coastal areas, such as some localities along the coast of France or in the Venice Lagoon, the biomass annually harvested is much greater (up to 2 orders of magnitude) than in Nueva Bay (Morand and Briand 1996) and compost production is economically sustainable. Even though the utilisation of drift seaweeds for compost production could not be economically justified, it should be considered as one of the environmental alternatives to land disposal.

The harvesting of drift macroalgae impact the coastal and terrestrial ecosystems by removing between 100 and 400 cubic meters of sand per season, accelerating the erosion process and changing the topographic profile of the beach. The seaweed collection would also affect the subtidal communities through the removal of the reproductive structures as well as the organic matter itself and associated nutrients. Other possible impact of harvesting is related to the structure and trophic dynamics of the associated communities (Kirkman and Kendrick 1997) such as the ″chorlo″ (*Charadrius falklandicus*) and the ″playerito″ (*Caladris fuscicollis*) that feed on the wracks of *Codium* spp. (Bala, pers. comm.).

In spite of these impacts, the Municipality will probably continue with the harvesting of the seaweed wracks in order to guarantee the recreational use of the beach during the summer months. In order to minimize the detrimental impact of this activity we recommend:

a) Harvest the macroalgal wrack using a more selective technology to avoid collecting the amount of sand being collected with the machinery, b) Initiate harvesting the macroalgae wrack early in the spring in order to remove the fertile individuals of *U. pinnatifida*, thus, decreasing the amount of zoospores of this invading species; c) Compost the wrack for use as soil amendments, decreasing the excessive soluble salts concentrations in the treated soils and recovering, in part, the cost of harvesting.

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