Benthic marine algae as reflection of environmental changes in the Northern Adriatic Sea

Ivka M. Munda

Scientific Research Centre of the Slovene Academy of Science and Arts, Ljubljana, Slovenia

Abstract

The northern Adriatic Sea is an unstable environment with wide seasonal and also interannual variations of the thermohaline regime, which is allied to the changeable current system and atmospheric conditions. There are likewise changes in the underwater illuminance and sedimentation rate. A complex interplay of these factors is reflected in the benthic algal flora and vegetation both regarding its seasonality and annual changes. There is, however, a highly dynamic situation in the benthic environment, which is overshadowed by anthropogenic disturbances, such as pollution, eutrophication and also mechanical damages. There is a general trend of reduction of fucoid stands, both in the eulittoral (*Fucus virsoides*) and sublittorally (*Cystoseira* and *Sargassum* species), in spite of transitional reinstallments. They are locally replaced by populations of ephemeral species. Several species with boreal affinities have not been found in recent surveys, while certain tropical species have increased in quantity.

Our findings are compared with the historical floristic data of Paul Kuckuck from the end of the 19th century, revealing a drastic reduction in the number of algal species, particularly in the Rhodophyta and Paeophyta.

Introduction

Marine algae are good descriptors of coastal environments. Changes of their associations, zonation patterns and floristic diversity are obviously linked to habitat modifications due to anthropogenic impact and variations of temperatures and salinities, light conditions as well as other abiotic ecological factors.

The northern Adriatic is a shallow shelf area and is regarded as the most dynamic basin of the entire Mediterranean Sea. It is characterised by a strong river run-off and wide seasonal and interannual variations of temperature and salinity (Russo and Artegiani, 1996; Artegiani *et al.*, 1997). It receives fresh water through the North Italian rivers (Po, Adige, Tagliamento, Isonzo), which carry a heavy load of organic and inorganic pollutants into the shelf. Pollution - and eutrophication - induced changes of the benthic algal flora and vegetation of this area were already reported (Munda, 1982b; 1993a,b; 1996). There are likewise changes related to the sedimentation rate, turbidity, and prevailing currents, which are linked to atmospheric conditions. During the last few years thermohaline properties within the northern Adriatic have changed (c.f. Malačič *et al.*, 2006), which may be linked to the seasonal and interannual variations of the benthic algal flora and vegetation.

STUDY AREA AND ECOLOGICAL CONDITIONS

Algological studies were carried out within the eastern area of the Gulf of Trieste, following others along the Istrian coast (Rovinj with surroundings), see Figure 1.

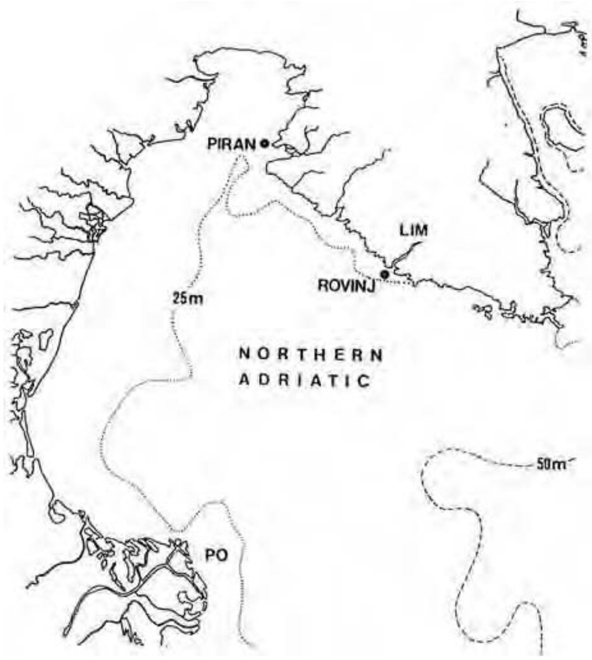

Fig. 1. Map of the Northern Adriatic coast.

Throughout the shallow Gulf of Trieste soft substrata prevail. There are alluvial Holocene deposits of silt, clay and fine-grained sand. This gulf is isolated from the rest of the northern Adriatic by a shoal, running from Grado to Salvore. It lies on the junction of the Istrian carbonate platform and Karst in the east, and the Friuli plain in the west. Between the river Timava and the town of Trieste extends a nearshore Karst area of Cretaceous limestone, with numerous freshwater springs. Eastwards from an accumulation area at Muggia, the coastal slopes are formed by Paleocene flysch all the way to Salvore. In localities dominated by hard substrata the coast slopes gently to about 9 m depth and from there on steeply towards the sediment bottom.

The bays of Piran and Koper where algological observations were carried out have high sedimentation rates. The detritial material originates from flysch, while the river Isonzo carries limestone material in the form of coarse grained sand and gravel into the western area of the gulf. The depth in its central area does not exceed 25 m and it contains approx. 9 km^3 water (Orožen Adamič, 1981). The tidal range is 97 cm in average, the highest for the entire Adriatic Sea.

The bottom topography within the gulf (Ranke, 1976) is responsible for the course of the main currents (c.f. Zore Armanda, 1968). A regular circular subsurface current transfers river-born and urban pollutants within the gulf (Mosetti, 1972; 1988; Stravisi, 1983; 1988) while local currents of a changing direction were reported by Rajer (1990). There are likewise seasonal and annual variations in the surface circulation. The discharge of the Po river greatly determines the current conditions as well as the physical and chemical gradients within the area, affecting the formation of a peculiar circulation. A line between the Po river mouth and Rovinj separates two gyres, a cyclonic north, and an anticyclonic south of this line (Zore Armanda and Vučak, 1984).Variations in the current system are also highly dependent on the bora wind, which blows in an offshore direction (Mosetti, 1972; Zore Armanda and Gačič, 1987) and are also related to recent changes in the atmospheric circulation.

Hydrographic data within the Gulf of Trieste are currently registered at the Marine Biological Stations at Trieste and Piran on offshore stations. Temperature and salinity data were also collected simultaneously with algal samplings at Piran (Munda, 1993a,b). During the 80-ties salinity values varied in average between 33 and 38 psu with minima between June and August and maxima from January to April. They usually increase with depth. Temperatures within the surface water layers exhibited minima between February and March with values from 6° to 7°C and maxima in July and August with approx. 25°C. During the time of summer stratification water temperatures decreased with depth and the opposite was found during winter. Homeothermic conditions were usually found between April and May (Figure 2a,b). Recent seasonal and annual measurements of temperatures and salinities (Malačič *et al.*, 2006) for the years 1991 to 2003 (Figure 3) revealed a yearly temperature increase from 0,12 to 0,23°C per year for summer at the surface, and of 0,22 to 0,23°C at 10 m depth.

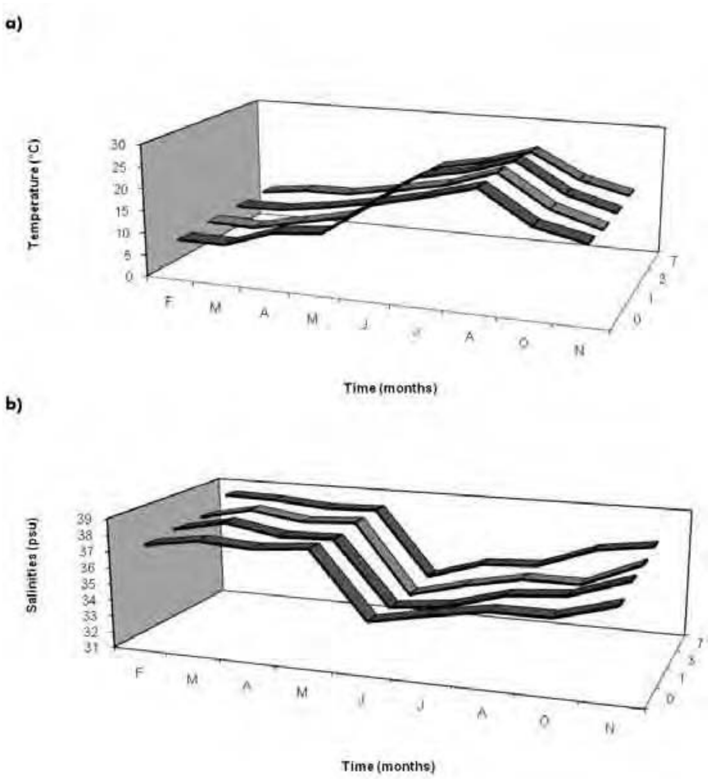

Fig. 2. Seasonal distributions of a) temperature, and b) salinity, at different depths near Piran in the 1980 s.

Winter temperatures showed an increasing trend from zero to 0,1°C per year. Interannual changes of annual temperatures in the surface water layers of the northern Adriatic, as estimated from long-term statistical analyses (Supić *et al.*, 2004), are related to the NAO and solar radiation. Salinity and density values in the surface water are mainly dependent on the major river discharge (Po, Isonzo).

Following recent measurements (Malačič *et al.*, 2006) the average yearly temperature minima increased to 9,19°C at the surface and to 9,17°C at 10 m depth, compared to data found by Munda (1993 a,b) of 7,7°C to 7,8°C during the eighties. Average yearly temperature maxima were reported as 25,0°C for the surface and 22,6°C for 10 m depth. Newer measurements for 2007 revealed, however, a yearly minimum of 10,1°C and a maximum of 26,5°C at the surface (Faganeli, pers. comm.).

Surface salinities show wide seasonal and interannual variations. They are influenced by the Adriatic circulation and changes in the river input. Average salinity values during the last decade ranged between 32,8 psu and 38,0 psu at the surface and 36,7 psu and 38,0 psu at 10 m according to Malačič *et al.* (2006).

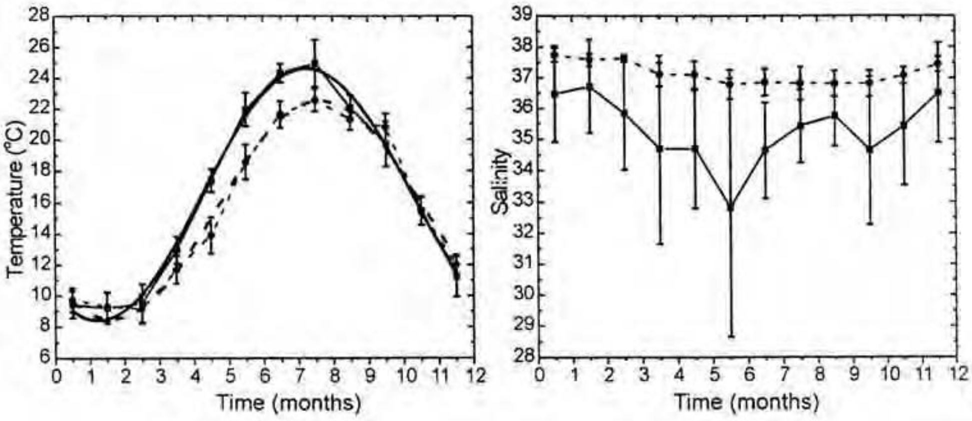

Fig. 3. Monthly temperature and salinity in the period 1991 – 2003 at depth of 0,3 m (solid lines with squares) and 10 m depth (dashed lines with dots) (after Malačič *et al.*, 2006).

SPATIAL, SEASONAL AND INTERANNUAL VARIATIONS OF THE BENTHIC ALGAL FLORA AND VEGETATION

The benthic algal flora and vegetation seems seriously threatened by environmental changes, both abiotic and biotic. Here remains the fundamental question about effects of global warning on the entire benthic environment, in particular on the subsurface habitats. Adverse effects on benthis algae are:

1. a decrease in species richness;
2. disappearance of large, canopy-forming species, first of all fucoids;
3. decrease in stratification;
4. disturbed seasonality.

Transitional recovery processes involve:

1. an increase of taxa;
2. increase of cover and
3. a greater complexity in stratification.

Fucoids, first of all representatives of the genus *Cystoseira*, are the main habitat-forming species in the Adriatic as a whole. *Sargassum* species are limited mainly to the lower water levels, while the endemic fucoid *Fucus virsoides* occupies the narrow eulittoral zone. It is regarded as a glacial relict, with *Fucus spiralis* as its Atlantic counterpart and best represented in the northern Adriatic. Its quantity decreases southwards along the eastern Adriatic coast.

Vegetational changes within the northern Adriatic basin are first of all due to the disappearance and / or reinstallment of the fucoid stands where also the main algal biomass is concentrated. They are rather sensitive indicators of environmental changes. Their disappearance along the Istrian coast in the seventies (c.f. Munda, 1972; 1979; *versus* Munda, 1980; 1993 a,b) was attributed to the drastically increased pollution and eutrophication (Munda, 1996).Within the Gulf of Trieste these vegetational changes were less severe and fucoids exhibited a patchy distribution (Munda, 1991). On the basis of field observation a sensitivity scale for the main fucoids was worked out (Munda, 1982b), ranging from *Fucus virsoides* over *Cystoseira compressa* and *C. barbata* to *C. crinita*, *C. corniculata* and *C. amentacea*, and finally to *Sargassum* species, as the most sensitive to environmental stresses. *In vitro* experiments also revealed a sensitivity of *Cystoseira* species (*C. compressa*, *C. barbata*) higher than *Fucus virsoides* towards decreased salinities, elevated temperatures and nutrient enrichment. Field observations were in agreement with these still partly unpublished findings (c.f. Munda, 1982a).

The zonation patterns and leading algal associations were first of all observed on hard substrata of allochthone limestone rocks and on flysch. The eulittoral slopes are only locally covered by the endemic *Fucus virsoides*, which has a patchy distribution in the area. Schemes of zonation patterns on a shore depleted of *Fucus virsoides* and another dominated by fucoids are presented in Figures 4 and 5.

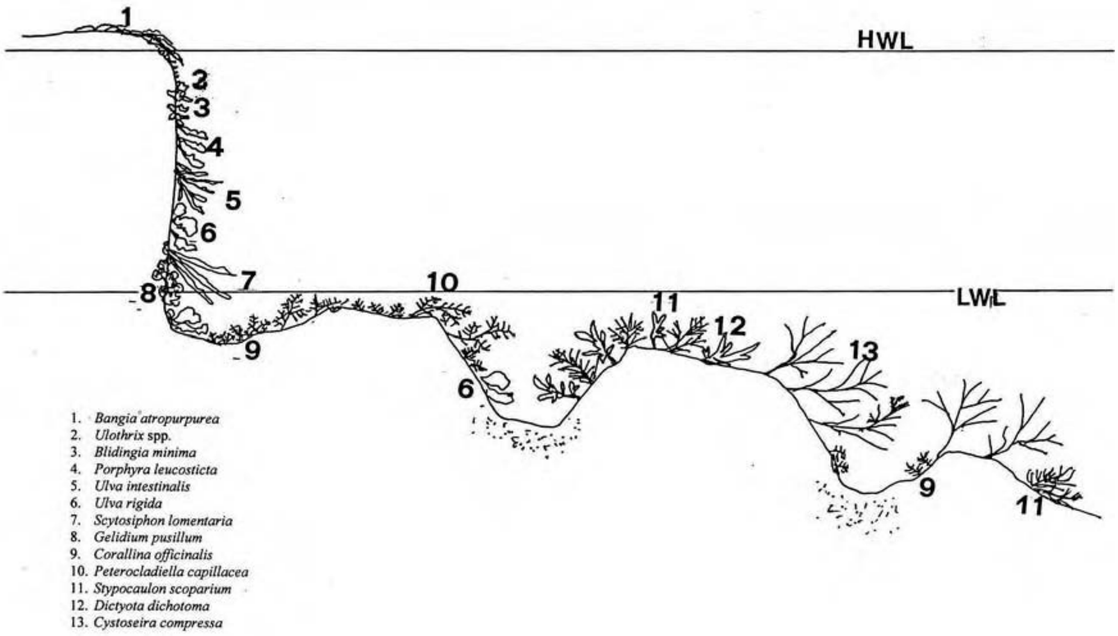

Fig. 4. Algal zonation pattern without *Fucus virsoides*.

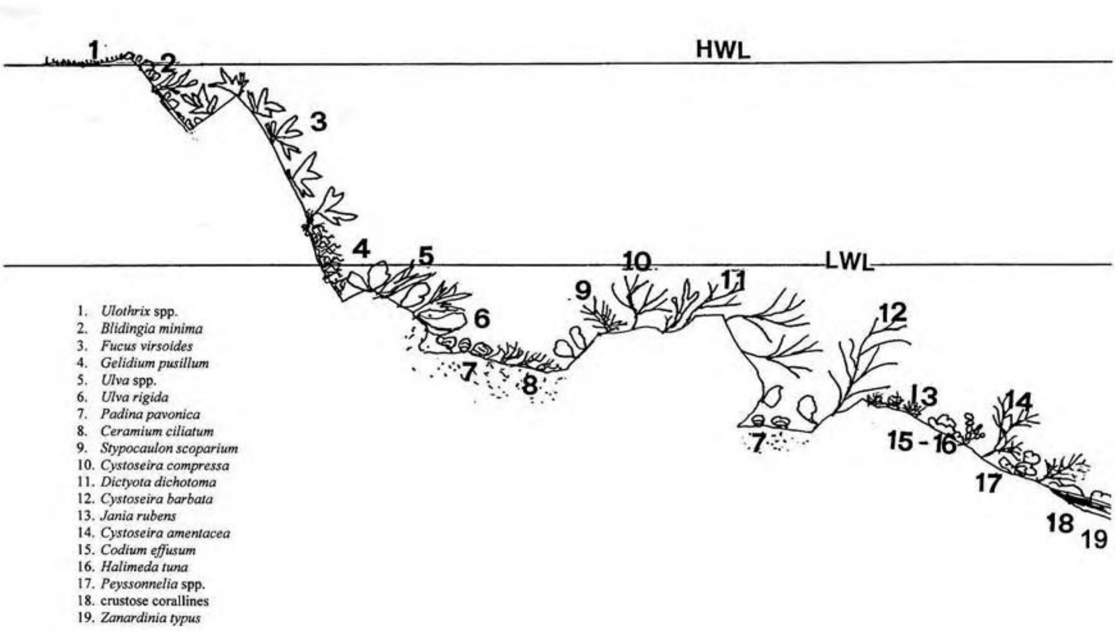

Fig. 5. Algal zonation pattern dominated by *Fucus virsoides*.

Recent algological studies along the eastern area of the Gulf of Trieste revealed both seasonal and annual variations in the benthic algal flora and vegetation. The seasonal and depth distribution of the main algal groups, expressed as number of species, is presented in Figures 6a,b and 7. Conditions along the western area, where soft substrata prevail, are described by Falace and Bressan (2003).

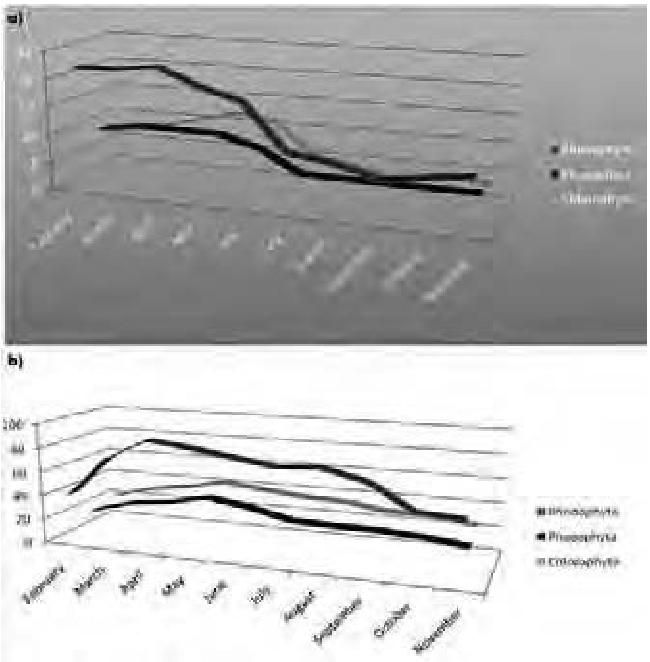

Fig. 6. Number of species – seasonal dynamics a) eulittoral, and b) sublittoral (Gulf of Trieste).

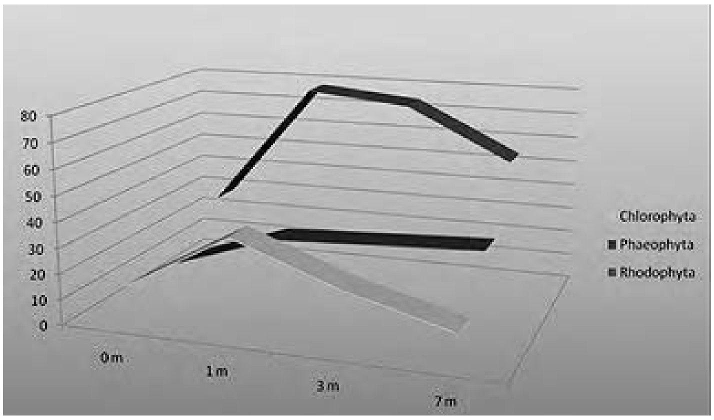

Fig. 7. Number of species in relation to depth (Gulf of Trieste).

In most rocky sites *Fucus virsoides* is replaced by diverse ephemeral species during spring. They form distinct zones with the following vertical sequence: *Bangia atropurpurea*, followed downwards by a belt of *Ulothrix* species, and even lower down by *Porphyra leucosticta*, *Blidingia minima*, a mixed belt of diverse *Ulva* species, *Ulva rigida* and lowermost *Scytosiphon lomentaria*. These slopes are usually clean during summer. *Fucus virsoides*, if present, forms a conspicuous four-layered association (c.f. Zavodnik, l967; Munda, l972), with crustose and dendritic species in the undergrowth, and mainly green algae within the layers of companion species and epiphytes. In some sites it is replaced by perennial turf-like mats of *Gelidium pusillum*.

Around the eulittoral/sublittoral junction a prolific vernal red-algae association occurred in most sites, formed by representatives of the Ceramiales. The dominant species within this conspicuous belt varied annually from e.g. *Ceramium ciliatum*, over *Callithamnion corymbosum* and diverse *Antithamnion* species to *Crouania attenuata*.

This vernal eulittoral vegetation was usually found between January and May and was best developed in April. There was, however, annual translocation in the appearance and disappearance of the individual belts, which cannot be attributed only to the influence a single environmental factor (e.g. the *Porphyra* belt could be absent, the appearance of *Bangia* delayed, the *Scytosiphon* belt joined by *Petalonia* species, the relative proportion of *Callithamnion corymbosum* within the vernal red algae belt increased).

The intertidal *Fucus virsoides* belts recently increased in width and again spread throughout the area. This transitional recovery was followed by a new destruction. The same was true of the sublittoral *Cystoseira* populations. There is, however, a highly dynamic situation in the upper water layers. In spite of transitional reinstallments there is a clear trend of a progressing reduction of fucoid stands in the northern Adriatic. Several stenoecious *Cystoseira* species occurred in this area mainly in patches, in between diverse mixed populations e.g. the endemic Mediterranean *Cystoseira barbara*, *C. amentacea*, *C. crinita* and *C. schiffneri*. Only *Cystoseira compressa*, a species of boreo- Atlantic affinity, was still rather prolific and formed a separate association in the upper sublittoral. It is noteworthy that the same species remained on the Côte des Albères, where all other *Cystoseira* and *Sargassum* species were erradicated (Thibaut *et al.*, 2005). The former *Cystoseira* associations are being replaced by those of diverse cosmopolitic species, with a lower structural capacity, such as by *Dictyota dichotoma*, and *Stypoaculon scoparium*. This succession means a reduction of floristic diversity and decrease in stratification. In some sites the tropical Atlantic species *Alsidium corallinum* formed dense populations in the sublittoral, replacing Cystoseirae, and the same was true of *Halopythis incurvus*.

As an example of interannual variations the appearance and subsequent disappearance of prolific belts of the invasive Atlantic species *Codium fragile* subsp, *tomentosoides* could be mentioned. On some allochthone rocks annual variations were likewise obvious with changes from crustose brown algae to green- algae mats. In a little harbour in Piran free floating algal mats changed yearly from e.g. *Acinetospora crinita*, over *Percursaria percursa* to diverse *Ulva* species (*Ulva intestinalis*, *U. clathrata*, *U. prolifera*) indicating a shift from species with warm water affinity over boreo Atlantic to cosmopolitic ones.

On gently sloping flysch rocks in the eulittoral, continuous mucus mats of diatom colonies locally replaced macroalgae in the spring (dominated by *Licmophora paradoxa*) to be reduced or absent the next year. It is noteworthy, however, that interruptions of the macrophytobenthos by microphytobenthos (diatoms and Cyanobacteria) are characteristic of this part of the northern Adriatic Sea.

In connection with the problem of global warming and the increased water temperatures in the upper water layers, the reappearance of the pantropical *Sargassum* species is noteworthy, as well as the frequency of *Padina pavonica*, *Asperococcus* species, *Hypnea musciformis*, dense sublittoral mats of *Acinetospora crinita*, along with an increased frequency and upward migration of some pantropical green algae (e.g. *Anadyomene stellata*, *Halymeda tuna*, *Valonia* species, *Flabellia petiolata*, *Bryopsis muscosa*). Some tropical Atlantic red algal species, as *Chyllocladia verticillata*, *Botryocladia botryoides*, *Compsothamnion thuyoides*, *Callithamnion corymbosum*, *Mesophyllum lichenoudes*, *Dasya corymbifera* increased in quantity during the last few years and were locally dominant. The invasive species *Asparagopsis armata* appeared as its tetrasporophyte *Falkenbergia rufolanosa*, which forms wide mats in the upper sublittoral and occurs also as an epiphyte on diverse macroalgae, while the gametophyte is limited to the Middle and South Adriatic.

On the other hand, a decrease in species with boreal affinities can be noticed. Several species, still mentioned by e.g. Furnari *et al.* (l999) for the Gulf of Trieste, were not found during recent surveys, such as e.g. *Bonnemaissonia hamifera, Aglaothamnion gallicum, Bornetia secundiflora, Brogniartella byssoides, Callithamnion tetragonum, Seirospora interrupta, Ceramium echinotum, Ceramiumn secundatum, Callophyllis laciniata, Audouinella subpinnata, Chondria coerulescens, Halarachnion ligulatum, Gymnogongrus griffithsiae, Erithroglosum sandrianum, Sphaerococcus coronopifolius* and some *Polysiphonia* species among the red algae. Fewer brown algal species were likely to disappear: e.g. *Arthrocladia villosa*, *Cladosiphon zosterae*, *Elachista intermedia*, *Herponema velutinum*, *Myriotrichia clavaeformis*, *Petaloia zosterifolia*, *Kuckuckia spinosa*, *Hincksia fuscata*.

It is noteworthy, however, that in this coldest area of the Adriatic Sea numerous species with a boreal affinity are still well represented and conspicuous, first of all representatives of the Corallinales.

LONG-TERM CHANGES

As an example of long-term changes of the benthic algal flora and vegetation, conditions along the Istrian coast (surroundings of Rovinj) will be mentioned. There was a prolific benthic algal flora and vegetation in the sixties (Munda, 1972; 1979) with a regular fucoid zonation (ranging from *Fucus virsoides* over diverse *Cystoseira* species to *Sargassum hornschuchii* and *S. acinarium*), as well as a prolific vernal red-algae vegetation. It was totally deteriorated in the seventies, but a partial reinstallment was found 20 years later.

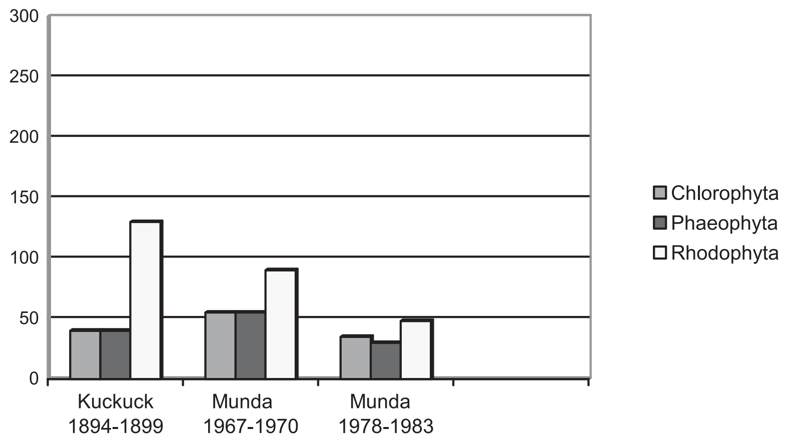

Fig. 8. Number of species recorded in the Rovinj area.

Previously, at the end of the 19th century (l894-l899), the Germain phycologist Paul Kuckuck from Helgoland collected marine algae around Rovinj. From a reconstruction of data from his unpublished diaries (see Munda, 2000) it became obvious that there was a rich algal flora at his time, when the environment was still undisturbed. In comparison with Kuckuck's records a floristic impoverishment occurred from the end of the 19th century to the sixties within all algal groups. About 24 % of the red algae and 30 % of the brown algae recorded by Kuckuck were not found in the sixties, when the vegetation was still prolific and apparently undisturbed. These long-term floristic changes can be, however, attributed to ecological parameters other than pollution and eutrophication or other forms of anthropogenic disturbances. Such decisive parameters are water dynamics, temperature and salinity regimes, sedimentation, turbidity, and sand-movements, resulting from short and long-term climatic changes (e.g. Vatova, 1934; Zore Armanda, 1991; Zore Armanda *et al.*, 1991; Supić *et al.*, 2004; Malačič *et al.*, 2006).

A further drastic reduction of the Rhodophytan flora by about 50 % occurred in the seventies. The main floristic impoverishment was found among the *Ceramiales.* Floristic and vegetational changes between the sixties and seventies were, however, extreme, resulting in a total deterioration of the fucoid populations. In comparison to Kuckuck's times, the overall number of recorded species decreased by more than one half. The Rhodophyta were most strongly affected with a loss of 62 % of the species, followed by the Phaeophyta and Chlorophyta with 53 % and 33 % respectively.