Colonization and Disappearance of *Mytilus galloprovincialis* Lam. on an Artificial Habitat in the Mediterranean Sea

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A *Mytilus galloprovincialis* population, settled on a new artificial habitat at 12 m depth in the Central Tyrrhenian Sea, was investigated for 10 years. The new substratum, located at a depth lower than the preferential range of the species, was colonized temporarily by mussels which reached very high densities and dominated the benthic community from their colonization until the third year. The length-frequency distribution analysis showed a progressively complex population structure with up to three cohorts. The yearly recruitments were observed once a year in spring. The growth curve provided a maximum length higher than that reported for shallow waters. Nevertheless, the gregarious habits of mussels and the reduced water movement caused edaphic modifications of the substratum, which was covered progressively by sediments and biodeposits (pseudofaeces). Consequently, the population structure was affected by a reduction of the newly recruited cohorts, and mussels disappeared after 5 years of colonization. This may be explained by the reduction in the substratum available for the first settlement (hydroid covering), as well as by the modification of the surface required for final settlement.

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Introduction

The mussel *Mytilus galloprovincialis* Lam. is widely distributed in meso and eutrophic waters of the Mediterranean Sea. It is fairly common in harbours and also in open waters, where it may characterize a stable ' facies ' on rocky substratum from 0 to 5 m depth (Bellan Santini, 1969).

In the Mediterranean Sea, mussel assemblages have been studied in detail in the harbours of Civitavecchia (Ardizzone *et al.*, 1977), Bari (Marano *et al.*, 1980), the Gulf of Naples (Renzoni, 1962, 1963), the Gulf of Castellammare (Sicily) (D'Anna *et al.*, 1985), and the Mar Piccolo of Taranto (Tursi *et al.*, 1979). Along the Ligurian coast, *M. galloprovincialis* was studied as a fouling colonizer on panels submerged in the

harbours of Imperia, Genova and Savona (Relini & Ravano, 1971). Mussels were found to be the dominant species up to 5 m depth in these eutrophic waters with abundant phytoplankton. They were able to tolerate some industrial discharges but, in very polluted areas, they were substituted by *Mytilaster minimus* Poli (D'Anna *et al.*, 1985). The preferential range of *M. galloprovincialis* is from 0 to 10 m depth and a zonation with depth was observed on vertical walls, with smaller mussels occurring at the surface and the larger mussels occurring at greater depths. In fact, interspecific competition was stronger in deeper waters due to the presence of other sessile organisms and the reduction of settlement recruitment (Tursi *et al.*, 1979). Furthermore, Renzoni (1963) also reports a reduction in the availability of mussel larvae below 10 m depth.

Mussels have also proven to be important colonizers of artificial substrata below 5 m depth, producing a harvestable biomass of economic importance (Bombace, 1981; Margus & Teskeredzic, 1986; Fabi *et al.*, 1989). In these conditions, the harvesting substratum is renewed continuously and therefore it is not known whether mussels are persistent in time. Some investigations have been carried out on offshore artificial substrata in the Central Tyrrhenian Sea (Ardizzone *et al.*, 1980), the Northern Adriatic Sea (Relini *et al.*, 1976) and the Ionian Sea (Relini *et al.*, 1976).

A mussel bed has also been reported in the Mediterranean Sea on the flats of a brackish embayment exposed to tidal currents at the Po River Delta (Ceccherelli & Rossi, 1984). Such a mussel population, which is unique for Italy, and similar to those reported in Northern Europe, has been extensively studied. In these conditions, tidal currents play an important role both in cleaning mussel valvae and in supplying food.

As for recruitment of *M. galloprovincialis* in the Mediterranean Sea, a peak of planktonic larvae was observed in spring, followed by a final settlement in the early summer (Renzoni, 1963; Marano *et al.*, 1980; Ceccherelli & Rossi, 1984). Little information is available on the growth rate, but mussels increased in size more rapidly in the eutrophic waters of the Northern Adriatic Sea, offshore from the mouth of the Po River (Relini, 1977).

From the literature reported above, data mainly concern the distribution and ecology of the mussel *M. galloprovincialis* and its settlement, recruitment and growth in closed embayments, such as harbours and brackish waters. Little is known about long-term mussel population dynamics in open waters and, in particular, on artificial substrata.

Therefore, the aim of this study was to examine the dynamics of a mussel population initially settled on a new artificial substratum over a period of 10 years. Mussels turned out to be the most important species, at least in the first years of colonization, even if the substratum was located at 12 m depth, below the species preferential range (Ardizzone *et al.*, 1989).

Materials and methods

Study area

The study area is located 2·7 km offshore at 12–14 m depth, 9 km north of the outlet of the Tiber River. The River transports effluents from Rome and is responsible for the eutrophic conditions (Figure 1). Salinity ranged from 35·5 to 36 due to the influence of the plume of the Tiber River; total phosphorous measured 0·3–0·5 μgat l^{-1} between February and April and the phytoplankton bloom occurred in late spring (March–June). The values of chlorophyll *a* ranged between 5 and 30 mg m^{-3}, and the mean transparency was 4·04 ± 2·26 m (Ardizzone & Giardini, 1982).
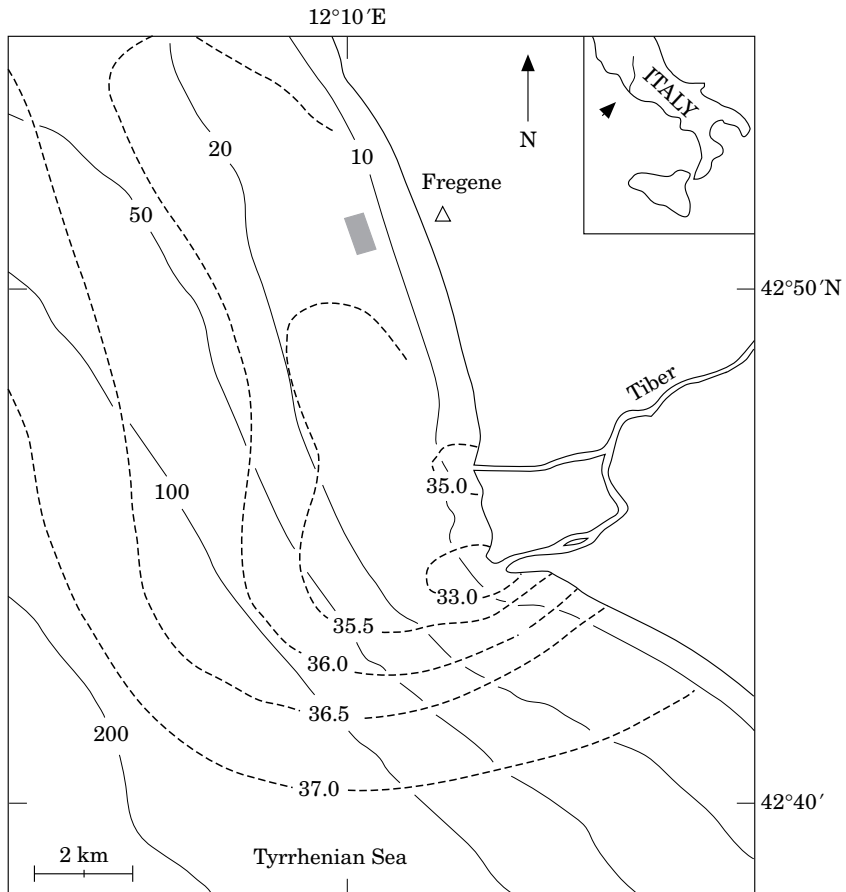
Figure 1. Map showing the study area and location of the artificial reef (shaded rectangle). ——, isobars (m); – – –, mean surface salinity (parts per thousand).

Artificial substrata were laid on silty sand (12–14 m depth) in March 1981 to increase the fish population for fishery purposes (Ardizzone *et al.*, 1989; Gravina *et al.*, 1989). They were composed of 280 concrete cube-shaped blocks (with 2 m sides) arranged in groups of five and covering an area of 6 ha (Figure 2).

Sampling procedures

Epibenthic samples were collected by SCUBA divers who removed a standard surface of 400 cm^2 on a vertical wall at various intervals from May 1981 to September 1991. The collected material was fixed and preserved in 10% buffered formalin. For each sample, mussels were counted, the shell length of each specimen was measured with a caliper and the biomass was estimated as dripped wet weight. Hydroid density was estimated as number of colonies on 400 cm^2. In fact, percent cover is difficult to estimate on a temporally variable surface, such as a mussel bed.

Zooplankton was sampled monthly for the first year in order to study the seasonal abundance of mussel larvae. Further occasional observations were carried out in the following years.
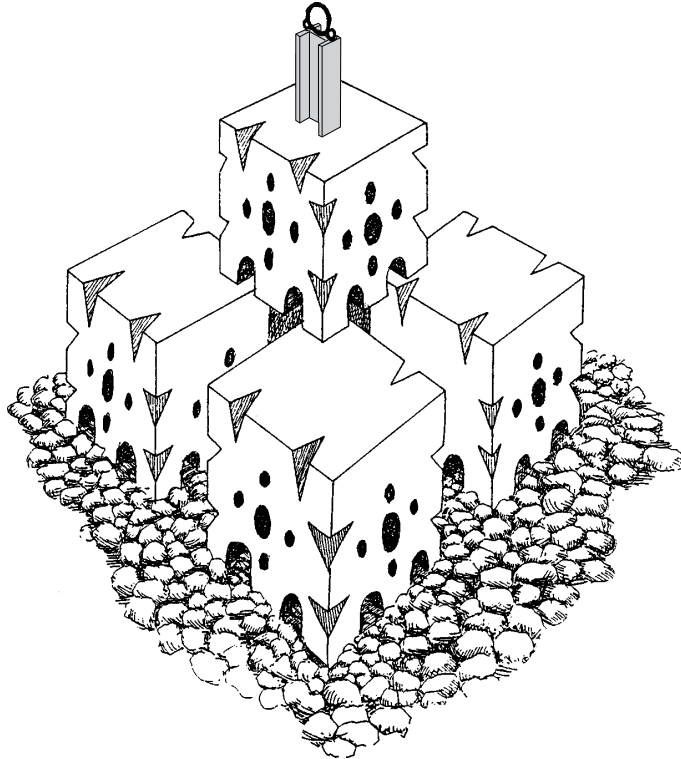
Figure 2. The artificial substrata. The cubes have a side length of 2 m.

Statistical analysis

The temporal trends of abundance and biomass of *M. galloprovincialis* were investigated. Population dynamics was studied using length-frequency data on classes of 0·5 cm. Preliminary cohort identification was done by means of Bhattacharya's method, while the growth curve was calculated using the Von Bertalanffy equation (Sparre *et al.*, 1989).

The linearized catch curve is one of the methods applied commonly in fishery population dynamics to estimate total mortality (*Z*) in temperate waters (Sparre *et al.*, 1989). Length composition data obtained from fishing samples are converted into age data by means of the Von Bertalanffy growth curve:

$$L_{(t)} = L\infty \ [1 - \exp(-K(t - t_0))]$$

where K is the ' curvature parameter ', which determines how fast the animal approaches $L\infty$, and $L\infty$ is the maximum length (asymptotic value).

Linearized through a log transformation, the slope of the resulting equation where:

$$y = \ln[N(L_1, L_2)/\varDelta_t \ (L_1, L_2)]; \ x = [t_1(L_1) \ + t(L_2)]/2$$

is equal to $-Z$. Thus, given a set of length-frequency data and the growth parameters K and L, it is possible to obtain an estimate of Z as the mortality due to both natural causes and fishing activity. In the present case, the fishing activity on mussels was absent and the value obtained for each sampling period indicated the natural mortality; that is, the
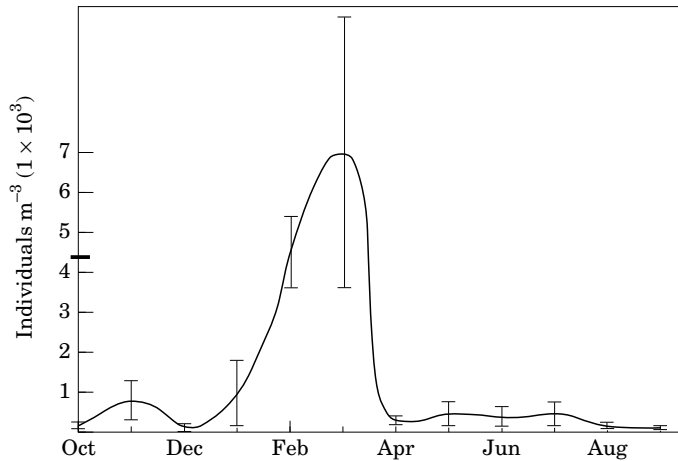
Figure 3. Temporal trend of mussel larvae. Bars indicate standard deviation.

numerical relationship between the newly-recruited cohorts and the old ones. Such values were plotted against time and defined as ' population stability rate ' (PSR). Any variation in time of the value of the PSR provides information on the status of the population, such as a trend to increase or to decrease in number owing to a change in relationship among cohorts.

Results

Settlement and recruitment

Planktonic larvae of *M. galloprovincialis* were found throughout the year attaining a peak in early spring (Figure 3).

The first macrobenthic organisms, mainly the hydroids *Obelia dichotoma* and *Bouganvillia ramosa*, were found on the new artificial habitat in May 1981. Young mussels were recorded first in June of the same year. Mussel pediveligers attached to a filamentous substratum, such as hydroid colonies (primary settlement). The young mussels (plantigrades) moved from the hydroids to the hard surface by means of their active foot (secondary settlement). Mussels first colonized the space around holes, cavities and the corners of the blocks (the surfaces more affected by water movement); only afterwards did they colonize the remaining surfaces (Ardizzone & Chimenz, 1982).

The temporal trend of mussel abundance showed a sudden increase during the first 2–3 months reaching the highest values in the autumn of the first year (12 625–12 450 ind m^{-2}, respectively, in October and November 1981). Mussels dominated the benthic community until the third year, reaching a peak of 13 525 ind m^{-2} in August 1982. Although the trends in biomass and abundance were similar, the first density peak in 1981 was associated with a very low biomass peak, due to the presence of only young specimens in the population (Figure 4). During the period of very high mussel density and biomass (1982–1983), a change in the substratum was observed as a result of the deposition of sediment and mussel mud between adult shells (Ardizzone *et al.*, 1989; Gravina *et al.*, 1989). From Late Spring to Summer 1983, an increase of sediment was observed and the mussel density and biomass decreased progressively. In Winter 1986, mussels had disappeared and were never observed again.
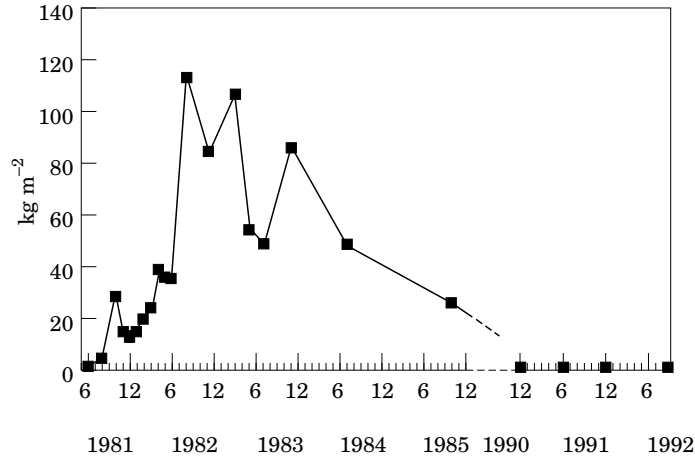
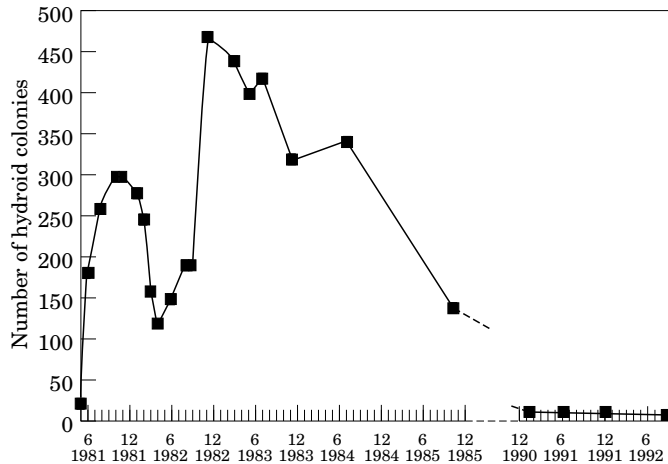Figure 4. Temporal trend of biomass of *Mytilus galloprovincialis*.

Figure 5. Temporal trend of number of hydroid colonies on a surface of 400 cm^2.

Hydroid covering showed a similar temporal trend, but the initial sudden increase preceded that observed for mussels (Figure 5). From Summer 1983, the hydroid density also decreased progressively, but a few scattered colonies were found on the artificial habitat until September 1992.

Population dynamics

The length-frequency distributions of mussels recorded in some of the sampling months are shown in Figure 6. Recruitment occurred early in spring (March–April) with new young mussels less than 1 cm in length. Only one cohort was present during 1981, while the recruitment of the second cohort occurred in Spring 1982. During the third year, the population structure became more complex and three cohorts partially overlapped each other. They persisted until 1985, but no mussel has been recorded on the artificial
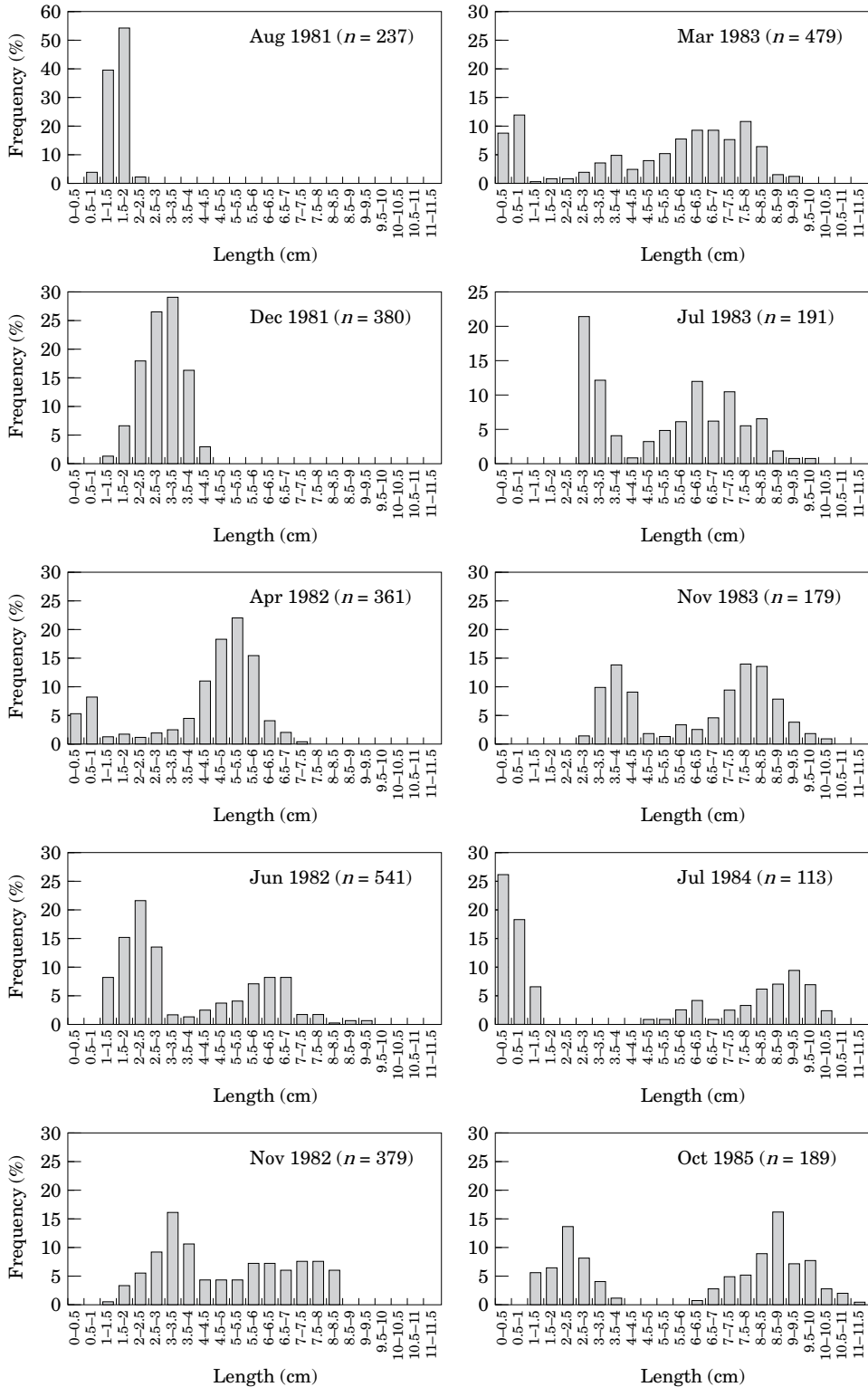
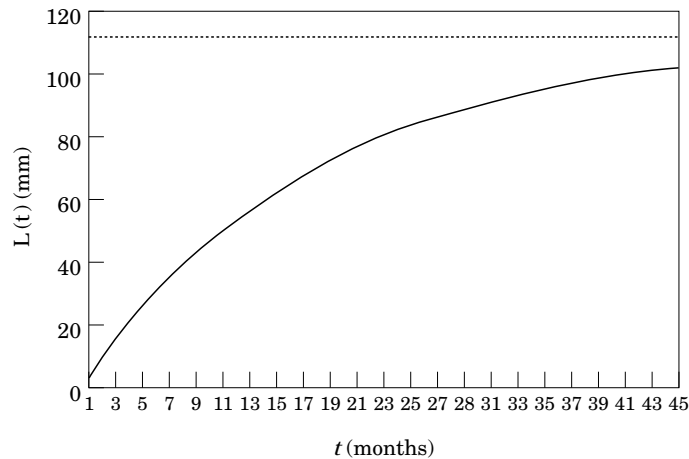Figure 6. Length-frequency distribution of *Mytilus galloprovincialis*.

Figure 7. The Von Bertalanffy growth curve. $L\infty = 111 \cdot 65$; $K = 0 \cdot 68$; $t_o = 0 \cdot 75$.

habitat investigated since June 1986. The modal class of adult mussels of the third year corresponded to values of 8–9 cm shell length, and the largest mussels were 11–11·5 cm in length.

Values of the Von Bertalanffy equation parameters and the corresponding growth curve are shown in Figure 7. The growth was rather fast during the first month; mussel length reached 30 mm 5 months after settlement and 70 mm in the second year; then the growth rate decreased and mussels attained 80 mm in length during the third year.

Concerning the PSR, a change in time of this value can indicate a change in structure of the population as follows:

(a) If the index increases in time, the recruitment or survival of the new cohort and/or the mortality of the aged cohorts are increasing. This results in a population mainly composed of juveniles up to the disappearance of the spawning adults.

(b) If the index is constant in time, the numerical relationship between young and aged cohorts is constant in time and the population is in an equilibrium state.

(c) If the index decreases in time, the recruitment or the survival of the new cohort and/or the mortality of the aged cohort are decreasing. The result is a population mainly composed of adults and, in case of absence of recruitment, the population can disappear.

The temporal PSR trend observed is of the third type (Figure 8). In fact, in the present case, the disappearance of the population could be due to a drastic reduction in the survival of the youngest cohort.

Discussion and conclusions

The continuous supply of mussel larvae was observed throughout the year with a marked peak in spring. Such results are in agreement with Renzoni (1963) and Marano *et al.* (1980), who also found large concentrations of larvae in early spring in the Gulf of Naples and in the Harbour of Bari, respectively. Furthermore, extended spawning in autumn–winter and early spring was observed in some Mediterranean areas, such as along the French coast, in the Adriatic and in Sicily (Renzoni, 1962; Boucart & Lubet, 1965; Hrs-Brenco, 1971; Valli, 1971; Ceccherelli & Rossi, 1984).
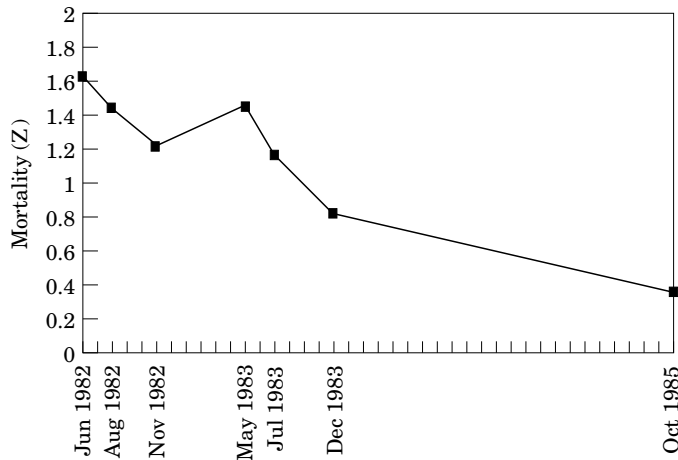
Figure 8. Temporal trend of the population stability rate (PSR).

Present observations show that mussel pediveligers found a suitable filamentous substratum for their primary settlement offered by hydroids which settled on the new artificial habitat 1 or 2 months earlier, and covered the surface rapidly with their colonies. The need for a filamentous substratum for the primary settlement of mussels (such as filiform algae, hydroids, bryozoans) is well known, both for *M. galloprovincialis* and for *M. edulis* (Seed, 1976; Lutz & Kennish, 1992). However, some evidence for direct settlement on adult mussel beds exists for *M.edulis* larvae (Grath *et al.*, 1988).

The secondary settlement observed during the investigation showed a defined spatial pattern. In fact, young mussels were able to discriminate between different exposures to water movement. They settled preferentially in the areas more affected by currents, an observation which agrees with the data of Eyster and Pechenik (1987) who studied the attachment of larvae in the laboratory.

The mussels' colonization of the new artificial habitat was very rapid and mussels had become the dominant species in the community by 6 months after settlement (Ardizzone *et al.*, 1989). In fact, during the first 2 years of the study, mussels found suitable environmental and biological conditions for settlement and survival. Subsequently, they decreased progressively and finally disappeared completely.

It was important to examine the main causes influencing the rarefaction and extinction of the mussel population. The eutrophic condition of the water enhanced the initial period of fast and dense mussel colonization, mainly by supplying food to larvae and adults. The rapid development of mussel populations under eutrophic conditions, both on fixed and renewable artificial substrata, has been confirmed in other Mediterranean areas (Relini, 1977; Bombace, 1981; Fabi *et al.*, 1989). Phytoplankton supply has been proven to be the most important factor in determining development and growth of larvae and adults of *M. edulis* (Lutz & Kennish, 1992; Seed & Suchanek, 1992). Also, in the present case, the annual trend of *M. galloprovincialis* growth is consistent with data reported for chlorophyll *a* concentrations by Ardizzone and Giardini (1982), at least during the phase of mussel dominance. Abundant food supply was responsible for the rapid growth rate and the highest values of shell length observed, as is also indicated by results from the Von Bertalanffy equation. The growth curve provided one of the highest

$L\infty$ reported for the Mediterranean Sea (Renzoni, 1963; Relini, 1977; Ceccherelli & Rossi, 1984; Fabi *et al.*, 1989). Considering that the year's values of chlorophyll *a* recorded in the study area were large enough to sustain the mussel population, it can be hypothesized that trophic resources were not a limiting factor for population survival.

The decrease over time of the PSR points to a change in the relationship between aged and newly recruited cohorts. Two main factors may be responsible for this trend; a reduction in the survival of young stages or a change in the mortality rate of the aged cohorts.

Seed and Suchanek (1992) summarized the main causes of natural mortality of mussels. Among them were physical parameters, such as temperature and salinity. These abiotic parameters normally fluctuate in the sea, without reaching the critical values observed in sheltered environments where seasonal massive death of mussels occurs (Ceccherelli & Rossi, 1984). On the other hand, predation is considered the most important biological cause of mortality in mussel species (Seed & Suchanek, 1992). In the case studied, the role of shorebirds as potential predators can be rejected due to the depth of the mussel settlement (10–12 m). Moreover, no large starfishes were observed on the artificial habitat, and the density of other important predators of mussels such as large crabs, octopi and gastropods did not increase significantly during the mussel regressive period (Ardizzone *et al.*, 1989).

Therefore, as no changes in the mortality rate of adults of *M. galloprovincialis* population were observed, the decrease over time of the PSR indicates a progressive reduction of the younger cohorts in relation to the older ones. The reduction of recruitment led to the ageing and, finally, the disappearance of the population. Two critical periods during the life history of mussels have to be considered in order to explain the reduction of the newly recruited cohorts; primary and secondary settlement.

An important reduction of the available substratum occurred during primary settlement, due to the decrease of hydroid covering during the winter of the third year. Thus, the reduction of the filamentous substratum suitable for first settlement may be one of the main factors affecting the density of young stages. Also, Dare (1976) concluded that for *M. edulis*, the efficiency of settlement is governed more by availability of suitable substrates than by plantigrade abundance.

As for the secondary settlement, competition during the post-larval phase and edaphic modifications could have affected the efficiency of recruitment. Very high population densities were observed during the first period of colonization when the population was growing. Consequently, intraspecific competition was disregarded as a factor controlling population structure, at least at the low densities recorded during the last years. As regards interspecific interaction, no other important sessile species competitive for space (such as barnacle, oyster, etc.) were observed during the regressive period. Finally, important edaphic modifications consisted of an increase in sediment particles and 'mussel mud' trapped beneath the shells of adults. Such an excessive amount of inorganic and organic matter could have affected the survival of young specimens by reducing their anchorage capability and the efficency of their filtering apparatus. As reported by Tsuchiya (1980) for *M. edulis,* the amount of pseudofaeces increases with increasing food concentration. In fact, when food is present in excess, as in the eutrophic waters investigated, the mussel utilizes the amount of food needed and eliminates the remainder as pseudofaeces. Furthermore, the large body size of mussels could also be responsible in determining the large amount of biodeposit (Tsuchiya, 1980). Large quantities of detritus accumulated between mussels can bury and smother animals, and

has been revealed as an important cause of mortality in other dense populations of *M. edulis* and *M. galloprovincialis* (Dare, 1976; Ceccherelli & Rossi, 1984).

The results above show that the *M. galloprovincialis* population, settled on an artificial substratum located below the preferential range of the species, was not persistent in time. The first recruitment on the new substratum led to a dense population which lived for 3 years. The decrease of the recruitment of young stages led to the progressive ageing and final disappearance of the population. These data can be related to the life-history strategies of mussels. Mussels are able to shed a very large number of eggs into the sea more or less continuously over an extended part of the year, and the larvae can spend a long time in the plankton (Lutz & Kennish, 1992). Furthermore, the larvae of *M. galloprovincialis* settle preferentially within 3 m of depth (Renzoni, 1962) and mussels successfully colonize the lowest intertidal areas exposed to strong water currents and to the excursions of other abiotic parameters. Both the large reproductive potential and the wide ecological tolerance allow mussels to colonize any newly available substrata. The fast growth rate can explain the rapid colonization and the high values of density reached. Notwithstanding this, the extinction of the population was essentially due to edaphic modifications. In fact, the species' gregarious habits and the water movement lower than that of the shallowest subtidal area were responsible for a progressive reduction in the suitable substratum for first and second settlement.

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