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A harvesting strategy for *Iridaea laminarioides* in central Chile

B. Santelices & R. Norambuena
Departamento de Biología Ambiental y de Poblaciones, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Casilla 114-D, Santiago, Chile

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Introduction

About 5000 t of dry *Iridaea* are exported annually from Chile for carrageenan extraction (Lopehandía, 1986), but inadequate biological knowledge prevents rational management of these species. As in the case of other economically important algal species in Chile, studies have been oriented either to understand the morphology and taxonomy of the species (Etcheverry *et al.,* 1981) or to characterize chemically the nature of the gels produced (Matsuhiro & Zanlungo, 1976a, b). Some of these species, such as *Iridaea laminarioides* Bory, are ecologically important in rocky intertidal communities (Santelices *et al.,* 1981) and careless harvesting might result in ecological damage and decreased production. Because of specific differences, ecological studies with species of *Iridaea* at other latitudes (Hansen & Doyle, 1976; Hansen, 1977, 1981; Adams & Austin, 1979) have limited application to the Chilean beds. Methods for field propagation or tank cultivation of species of *Iridaea* elsewhere (Waaland, 1973, 1976, 1982; Mumford, 1979; Mumford & Waaland, 1980) cannot be used in Chile, mainly owing to limited knowledge on the production ecology of the local species.

This study was designed to gather basic biological information on *Iridaea laminarioides* in central Chile for formulation of an optimum harvesting strategy for the species. This is considered a first step for a more comprehensive management program of this native resource. We first analyzed the temporal variations in standing stocks, reproductive pattern and gel content of intertidal populations in central Chile. Aided by field experiments, we then measured regeneration capacity of these populations to monthly harvesting and the recruitment capacity of juvenile fronds. All these data are integrated in a harvesting model for populations in central Chile.

Materials and methods

Study site

Field studies were done at Matanza (35°56′S, 71°53′W). This is a sandy beach with frequent rocky outcrops projecting seaward. Periodic sand invasion of the lowermost intertidal and shallow subtidal levels prevents high grazer densities in these habitats and favors algal communities with sand-resistant perennial phases. *Iridaea laminarioides* reaches high representation values in this type of habitat, forming a conspicuous belt extending from 0.4 m to 2.2 m above zero level (mean tide chart datum). In Chile, this type of habitat is frequently found in the stretch of coastline between 33 and 42°S (Santelices, 1980) and constitutes one of the preferred harvesting areas for intertidal crops of *Iridaea laminarioides.*

Temporal variations in standing stocks, gel contents and reproduction patterns of these populations were measured by removing all individuals within eight 0.25-m^2 quadrats haphazardly placed within the *I. laminarioides* belt. Eight quadrats were the minimum sample size required to obtain a "good" representation of this population (Mueller-

Dombois & Ellenberg, 1974). Sampling was repeated monthly from January 1984 to March 1985. The fronds collected were transported to the laboratory, washed in clean seawater to remove sand and epiphytes, separated by reproductive stages and wet and dry weights determined. Carrageenan content of the dried thalli was measured as described by Craigie & Leigh (1978). The ploidy levels of 30 freshly collected sterile fronds were determined using the resorcinol-acetal reaction (Craigie & Leigh, 1978, p. 123), which assumes that tetrasporophytes produce λ-carrageenan whereas gametophytes contain κ-carrageenan.

In order to measure recruitment rates of juvenile thalli, 16 permanent 0.25-m^2 quadrats were established in the field within the *Iridaea laminarioides* belt. All thalli inside each quadrat were manually removed, and the remaining crustose bases were burned. All algal species which recruited before, together with or after recruitment of the juveniles of *I. laminarioides* were allowed to persist in eight experimental plots but were removed from the other eight quadrats. The observations began in May, 1984 and ended in February 1985.

Regeneration capacity of harvested thalli of *Iridaea laminarioides* was measured in another 16 0.25-m^2 permanent quadrats from January 1984 to March 1985. Each month all fronds within a quadrat were cut 2 cm above the holdfasts, placed in previously numbered plastic bags and transported to the laboratory for weight determinations and gel-content analysis.

Results

Temporal stock variations and reproduction patterns

These intertidal populations showed seasonal growth variously affected by abiotic factors and by the reproductive activities of the population itself (Fig. 1). Stocks started increasing during winter (May–June) owing to the growth and maturation of cystocarpic thalli. After spore release, many cystocarpic fronds became perforated or necrotic because of soral losses and were eventually removed by water movement, decreasing the stocks by late winter (August). Stocks, now composed almost entirely of vegetative thalli, increased thereafter, reaching maximum values (1–1.2 kg·m^{-2}) by early summer (January). Desiccation during summer then reduced these stocks. Subsequent growth of new fronds during the next winter was achieved by regeneration from the holdfasts.

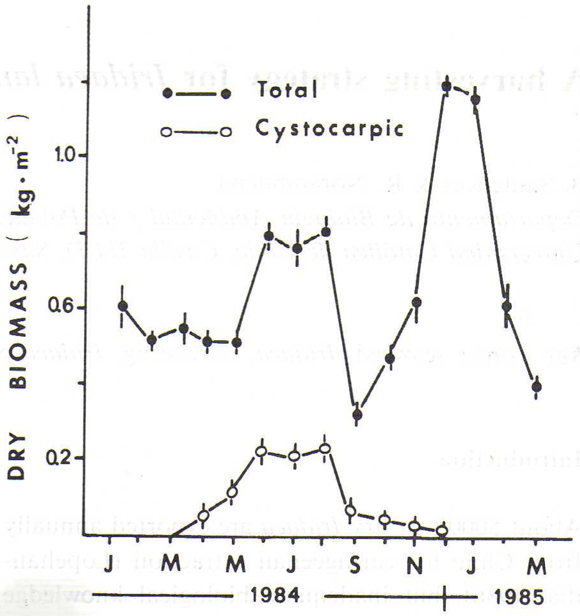

Fig. 1. Temporal variations of total and cystocarpic standing crops of the intertidal populations of *Iridaea laminarioides* in Matanza, central Chile.

The abundance of tetrasporophytic thalli was low during most of the year and only occasionally were fertile tetrasporangial thalli measurable in stock assessments. Resorcinol-testing of the vegetative population confirmed that gametophytic thalli were the most abundantly represented in this population (Fig. 2).

Recruitment

Recruitment of *Iridaea laminarioides* juveniles occurred if new substratum was made available, as in our removal experiments (Fig. 3). If the opportunistic algal species which first invaded the burned plots (*e.g., Porphyra columbina* Mont., *Ulva rigida*

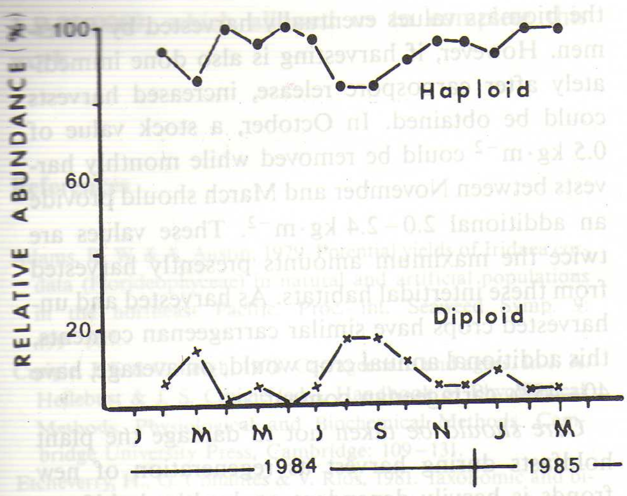

Fig. 2. Relative abundance of haploid and diploid thalli in the sterile population of fronds of *Iridaea laminarioides* in Matanza.

C.Ag., *Enteromorpha compressa* (L.) Grev.) were removed, growth of the new recruits of *Iridaea laminarioides* was significantly reduced as compared with growth in areas where the opportunistic species had been allowed to remain. Apparently the presence of opportunistic algal species reduced desiccation of the new individuals of *I. laminarioides*. The protective effects are important until the *Iridaea* juveniles attain cover values of 20–25% on these rocky surfaces.

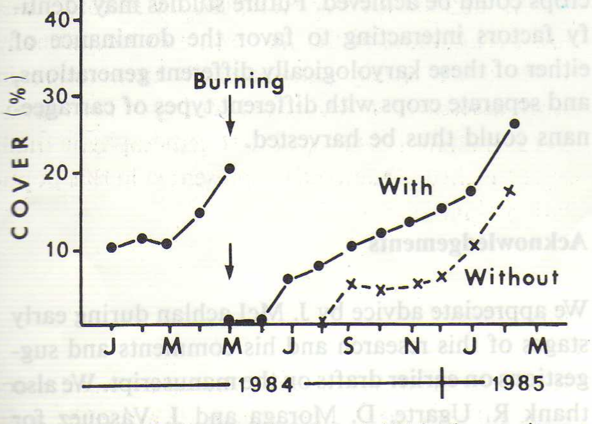

Fig. 3. Effect of accompanying algae (with) in the recruitment and growth of *Iridaea laminarioides* at Matanza. The species had a cover value of about 20% when the experimental plots were initially harvested and burned.

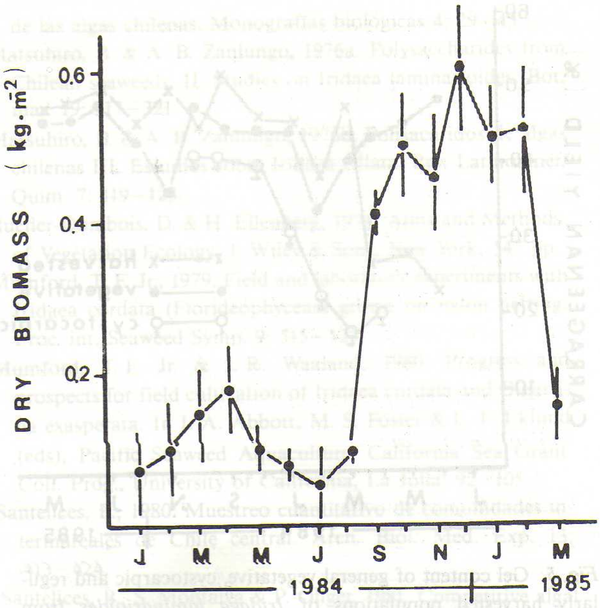

Fig. 4. Biomass production in populations of *Iridaea laminarioides* harvested monthly at Matanza.

Regeneration after harvesting

The sum of monthly harvests for a 12-month period indicate (Fig. 4) that productivity of these beds ranged from 3.3 to 3.7 kg·m^{-2}·y^{-1}. Between 65 to 70% of this biomass could be harvested in six months, between October and May. The plants that were harvested monthly remained vegetative.

Gel content

Carrageenan yields of the unharvested intertidal population varied (Fig. 5) from a minimum of about 35% in June and November to a maximum of 50% in October and January–February. Overall, average carrageenan content was 41% of the dry weight. These values were derived mainly from vegetative thalli, which dominated the population during all seasons. Gel contents of cystocarpic thalli, measured only from April to October, showed a seasonal increase from 20% during April–May to 40% in October. Tetrasporangial fronds, whenever present, had gel contents of about 45% except during November when the thalli were senescent and

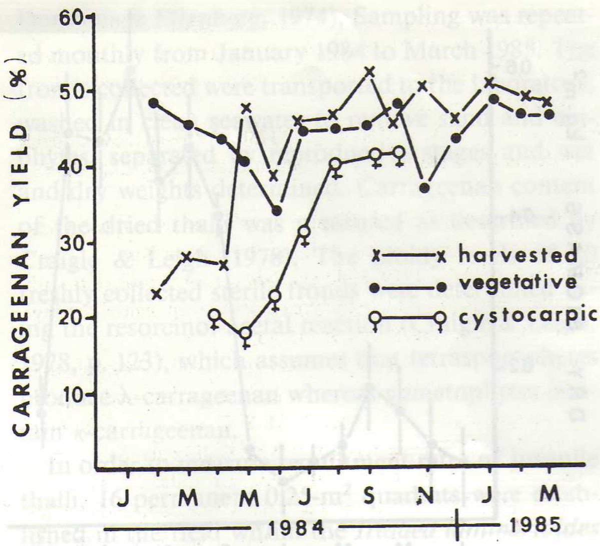

Fig. 5. Gel content of general vegetative, cystocarpic and regularly harvested populations of *Iridaea laminarioides* from Matanza.

necrotic and had gel contents of about 10%.

Gel contents of repeatedly harvested thalli were generally similar to the values found in unharvested populations, ranging from 25% to 50% and showing an annual average value of 41.5%. The only significant difference was an initial period, during February-April 1984, of reduced gel content in the regenerated thalli.

Discussion and conclusions

The combination of data obtained in this research indicates that the harvesting practices of *Iridaea laminarioides* presently extant in central Chile could be improved, resulting in preservation of the beds and increased biomass production. In central Chile, the species shows a seasonal cycle of growth with biomass accumulation between fall and winter and carpospore production by early spring. Stocks accumulated by that time may reach up to 0.8 $kg \cdot m^{-2}$. In the following months, stocks are reduced to about 0.5 $kg \cdot m^{-2}$ due to losses of mature cystocarpic fronds. Population growth is then maintained up to mid-summer when the naturally accumulated stocks reach 1.2 $kg \cdot m^{-2}$, which are the biomass values eventually harvested by fishermen. However, if harvesting is also done immediately after carpospore release, increased harvests could be obtained. In October, a stock value of 0.5 $kg \cdot m^{-2}$ could be removed while monthly harvests between November and March should provide an additional 2.0–2.4 $kg \cdot m^{-2}$. These values are twice the maximum amounts presently harvested from these intertidal habitats. As harvested and unharvested crops have similar carrageenan contents, this additional annual crop would, on average, have 40–45% carrageenan content.

Care should be taken not to damage the plant holdfasts during harvest as regeneration of new fronds is heavily dependent on healthy holdfasts. Juvenile recruitment occurred in denuded experimental plots, but production of harvestable stock was much slower than by regeneration from harvested plants. A similar phenomenon was reported by Hansen & Doyle (1976) for *Iridaea cordata.* Tagged individuals are revealing overwintering capacity of the holdfasts and longevity of at least three years.

It is interesting that this intertidal population, and also those 200 km further north (Hannach & Santelices, 1985), have a much higher component of haploid than diploid thalli. This provides the opportunity to gather resources containing mainly κ-carrageenan. Should other populations in central Chile be dominated by tetrasporangial (diploid) fronds, harvesting of λ-carrageenan-producing crops could be achieved. Future studies may identify factors interacting to favor the dominance of either of these karyologically different generations, and separate crops with different types of carrageenans could thus be harvested.

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