Stock assessment of the Agarophyte *Gelidium Sesquipedale* using harvest effort statistics

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Abstract

Divers operating from small boats hand-pluck the agarophyte algae *Gelidium sesquipedale* along the Portuguese coast for the extraction of agar. The available harvest effort statistics of two commercial beds, Cape Espichel and Azenha do Mar, were analysed to assess their use for resource management. The relationship of the catch per unit of effort with the cumulative harvest throughout the harvest season was used to estimate the species catchability, the pre-harvest standing stock and the annual exploitation rates. We showed that the combined use of these indexes is a powerful tool to manage this resource.

For example, in 1987, the high standing stock of Cape Espichel, the low exploitation rate and the low catchability indicated that the resource was underexploited probably due to bad sea conditions. On the other hand, the resource collapsed after 1989, due to a high exploitation rate of a standing stock depleted by severe winter storms. In Azenha do Mar, the high levels of exploitation rate and catchability in the year 2000 suggest that the resource may not recover for the next harvest season.

An obvious advantage of stock assessment based on harvest effort statistics is its low cost when compared to expensive field assessments. We give recommendations on the necessary information that should be included in the harvest logbooks of every *Gelidium sesquipedale* harvest zone of Portugal.

Abbreviation: catch per unit of effort - CPUE

Introduction

Since 1960, divers operating from small boats, using a low-pressure compressor and a hose, have plucked *Gelidium sesquipedale* tufts by hand for the extraction of agar along the Portuguese continental coast (Santos and Duarte, 1991). Harvest regulations exist to manage this resource. The harvest season is legislated from July to December, and the harvest effort is controlled by licensing the number of boats and divers operating within each of the six harvest zones into which the Portuguese continental coast is divided. The only harvest statistic that is published, and thus easily accessible, is the yearly harvest yield of each zone. Even though harvest effort data were collected for a number of years by the responsible authority (Direcção Geral das Pescas), these data were not analysed and are difficult to obtain.

Fishing effort and catch per unit of effort (CPUE) are fundamental statistics to manage fish populations (Ricker, 1975). When a single homogeneous population is being fished exclusively by one kind of gear, and when effort is proportional to the rate of fishing, it is well established that CPUE is proportional to the mean stock present. This ideal situation is unlikely to be the true situation for most fisheries, but the *Gelidium sesquipedale* harvest is very close to it. The distribution of the species along the Cape Espichel commercial bed did not show major heterogeneities (Santos, 1993), only one kind of gear is used to harvest the seaweed (hand-plucking by divers) and effort is proportional to the rate of harvest (see below). Abundance estimates of *Gelidium sesquipedale* derived from CPUE and harvest yields may be quite accurate providing that harvest effort and harvest yields data are accurate.

As far as we know, this is the first published report to use harvest effort data to estimate the standing stock of a commercial seaweed species. Harvest effort data were used to manage seaweed resources for the eastern Canadian Irish moss fishery (Pringle, 1981 and Pringle *et al.*, 1987), but the total standing stock was not estimated based on CPUE data. In other fisheries involving commercial diving, such as the abalone (*Haliotis* spp.) in British Columbia (Farlinger & Thomas, 1993), the loco (*Concholepas concholepas*) in Chile (Castilla *et al.*, 1998) or the holothurian *Isostichopus badionotus* in Venezuela (Buitrago & Boada, 1996), the harvest patterns and CPUE were used for stock assessment.

In this study, we gathered the available information on the time variation of both the *G. sesquipedale* harvest yields and harvest effort for zones 5 and 6. Harvest statistics were computed and analysed to assess their use in the resource management of the species. The CPUE was calculated and its relationship to cumulative harvest yield throughout the harvest seasons was analysed to obtain estimates of the *G. sesquipedale* standing stock. The rate of exploitation of the resource was also calculated and its time variation was analysed to assess patterns of over- or under-exploitation. We show that these simple, easy to collect statistics are a powerful tool for managing the resource.

Materials and Methods

The available *Gelidium sesquipedale* harvest-effort data were collected from Cape Espichel (zone 5), for 1986 to 1992, and from Azenha do Mar (zone 6), for 1999 to 2000. For these periods, each boat completed a logbook where data on the number of divers operating each day, the number of hours of diving, the location of the harvest and the daily harvest yields were collected. In zone 6, practically all the harvest yield of 1999 and 2000 originated from only one bed, located on the southern coast near Azenha do Mar. On the other hand, harvest zone 5 includes several commercial beds. An initial problem in analysing the logbooks of zone 5 was that sometimes the names of the beds written on the logbooks were impossible to locate. Each boat crew had their own name and sometimes the same site is named differently in different logbooks. Another concern was the heterogeneity of harvest zone 5, which included beds that were very far apart, and therefore exposed to very different sea conditions. Some beds are very heterogeneous, with low *G. sesquipedale* cover, and others that are more exposed are more homogeneous with high species cover. For these reasons we decided to concentrate the analysis of zone 5 on the bed located on the northwest coast of Cape Espichel. This is a very exposed site, where most of the harvest of zone 5 is made.

CPUE was defined as the amount of *Gelidium sesquipedale* (fresh weight) a diver collects in one hour. CPUE was calculated by harvest boat because the logbooks did not discriminate the amount of seaweed collected by each diver. The daily boat harvest was divided by the number of diving hours and by the number of divers in each boat, which can be only one or up to five.

The 'Leslie' method was used to estimate standing stocks (Ricker, 1975). By definition, CPUE during interval t is equal to catchability (q) multiplied by mean standing stock present during the interval t (N_t). Catchability is defined as the fraction of the standing stock, which is caught by a defined unit of the harvest effort:

$$CPUE_t = q\ N_t$$

The standing stock at time t, N_t, is equal to the standing stock before the harvest, N_0, less the cumulative catch during time t, K_t:

$$Nt = N0\text{-}Kt$$

Then,

$$CPUE_t = qN_0\text{-}qK_t$$

This equation indicates that CPUE during time interval t, plotted against the cumulative catch K_t, should give a straight line whose slope is the catchability, q. The X-axis intercept is an estimate of the standing stock before harvest, N_0, since it represents the cumulative catch if CPUE, and thus the population, were to be reduced to zero by harvesting.

The rate of exploitation, E, was defined as:

$$E = Y/N_0$$

where Y is the total harvest yield of the season.

Results

Harvest effort

Harvest effort statistics presented in Table 1 show that effort was generally higher in zone 5 than in zone 6. Both the total number of diving hours during the harvest season (total effort) and the total number of diving days were higher in zone 5. However, this last statistic is not a good indicator of effort because, when the sea is rough, a few boats may be working even though most do not harvest. The number of days when at least three boats go to sea is less variable and more related to the total number of diving hours (r = 0.98). In zone 5, the harvest season was longer in the first three years when it developed from July to November. In the last two years, the harvest season began later and ended sooner, and harvest effort decreased to its lowest level in 1991. The dives are longer in zone 6 because the commercial *Gelidium sesquipedale* bed is closer to the harbour than in zone 5. Not surprisingly, more boats work in zone 5 because the area of the commercial bed (345 ha) is much larger than in zone 6 (13 ha).

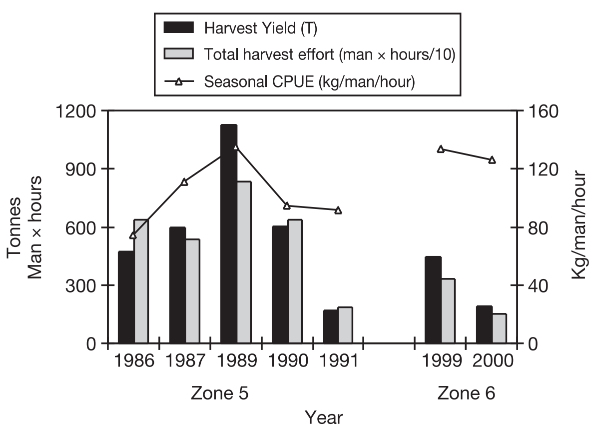

Fig. 1. Yearly variation of harvest yield, of total harvest effort and of seasonal CPUE in the *Gelidium sesquipedale* harvest zones 5 and 6.

Harvest yields were positively related (r = 0.90) to total harvest effort (Fig. 1). The harvest season CPUE, i.e. the fresh weight of *G. sesquipedale* a harvester collected in one hour of diving during that season was generally higher in zone 6 than in zone 5 (Fig. 1). CPUE followed the trends of both harvest yield and harvest effort except in 1991, and to a certain extent in 1987, when CPUE was high relative to the low values of harvest yield and harvest effort.

Relationships between CPUE and cumulative harvest yields

The variation of CPUE data was generally high (Fig. 2). In spite of the low coefficients of determination of regressions (R^2 varied from 0.08 to 0.19), highly significant relationships between CPUE and cumulative harvest yields were found (p varied from 7×10^{-14} to 0.02), except in 1991 (p = 0.283). Data were scarce in 1991 because harvest effort was very low (Table 1). In all cases, the CPUE decreased linearly with cumulative yields throughout the harvest season, allowing the estimation of the pre-season standing stock.

Estimates of the *Gelidium sesquipedale* standing stock were much higher in zone 5 than in zone 6 (Fig. 3), because the harvest area was larger. The standing stock of zone 5 increased to a maximum in 1989, decreasing afterwards to a minimum in 1991. In 1992, there was no harvest in zone 5 due to stock depletion. In zone 6, the standing stock was higher in 1999 than in 2000.

The exploitation rate generally followed the standing stock trends, except in 1987, when it was lowest (0.17), and in 1990, when it was highest (0.43). High values of exploitation rate were found in zone 5, 1990, when the standing stock was strongly decreasing (Fig. 3). Catchability was low

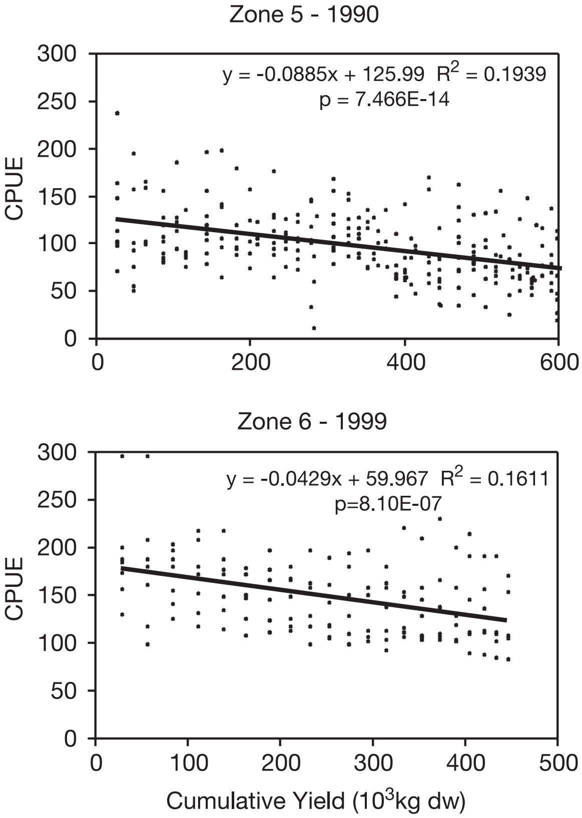

Fig. 2. Examples of the relationships between CPUE and cumulative harvest of *Gelidium sesquipedale* during harvest seasons of 1990 in zone 5, and 1999 in zone 6. Linear equations are presented with their coefficients of determination (R2) and significance values (p).

in 1987 and 1989 in zone 5, and in 1999 in zone 6. High values were obtained in 1990 and 1991 in zone 5, when the standing stock was at its lowest level, and also in 2000 in zone 6.

Discussion

The most important limiting factors for *Gelidium sesquipedale* harvest effort, and thus for harvest yield, which was highly correlated with effort, were bad sea conditions and low standing stocks. This species, as others of the same genus, develops on the most exposed coasts (Santelices, 1988) limiting the harvest to the days of calm sea. However, social and economic factors such as seaweed price may also limit the harvest effort. Low harvest effort in 1987 in zone 5, when the standing stock was high (Fig. 3), was probably related to bad sea conditions during the harvest season. This resulted in a low exploitation rate this year even though CPUE was high.

In contrast, low harvest effort of 1991 in zone 5 was due to low standing stock. The high value of CPUE in 1991 seems in contradiction with both the standing stock estimate and the harvest yield. The fact that the harvest season in 1991 was very short (Table 1) explains why this value is high. If the harvest season were longer, the season CPUE would certainly decrease. Harvesters stopped their activity, as they understood the resource was depleted.

	Year	Start season	End season	Diving days (*)	Boats	Average dive time (h)	sd	Total effort (man x hour)
Harvest zone 5 (345 ha)	1986	13 Jul	6 Nov	89 (31)	11	6.9	1.2	6,368
	1987	15 Jul	30 Nov	64 (32)	11	5.7	1.64	5,348
	1989	15 Jul	10 Nov	68 (45)	12	6.4	1.36	8,318
	1990	30 Jul	13 Oct	52 (34)	12	6.1	1.04	6,373
	1991	12 Aug	6 Sep	24 (11)	11	6.9	0.93	1,860
Harvest zone 6 (13 ha)	1999	20 Jul	9 Sep	21 (21)	7	7.4	0.87	3,340
	2000	1 Aug	31 Aug	13 (13)	6	7.7	0.58	1,530

*more than 3 boats

Table 1. Gelidium sesquipedale harvest effort data for Cape Espichel (zone 5) and Azenha do Mar (zone 6).

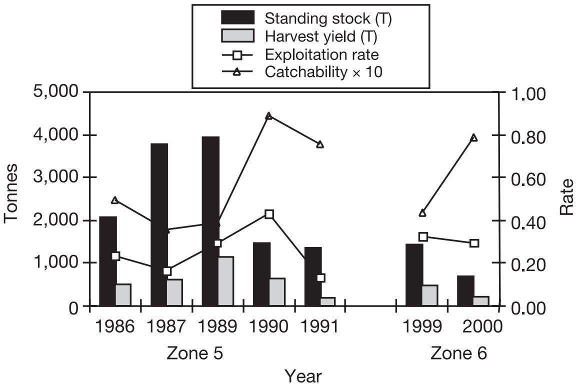

Fig. 3. Yearly variation of standing stock, harvest yield, exploitation rate and catchability of Gelidium sesquipedale in harvest zones 5 and 6.

Both standing stocks and harvest yields of *Gelidium sesquipedale* of Cape Espichel collapsed after 1989 to the point that no harvest was made in 1992. An immediate cause for the reduction of the standing stock from 1989 to 1990 was the severe storms of the winter. During this period, the intrinsic population processes that led to this collapse and their relations to the sea conditions are well documented in Santos (1994, 1995).

The exploitation rates estimated here showed a peak precisely in the harvest season of 1990, after the storms. In addition, the *Gelidium sesquipedale* catchability was highest, suggesting that too much was harvested in relation to the available standing stock (Fig. 3). These are clear indications that the resource was over-exploited and that its unfortunate combination with the environment conditions led to the resource collapse. The high levels of catchability and exploitation rate in 2000 in zone 6, suggest that the resource may not recover for the next harvest season (summer of 2001), particularly if there are strong storms during the current winter. On the other hand, in 1987 in zone 5, high standing stock, low exploitation rate and low catchability indicated that the resource was under-exploited.

The combined use of these indexes is a powerful tool to manage this resource. To obtain precise estimations of catchability, standing stocks and exploitation rates, the dispersion of daily values of CPUE data should be minimized. CPUE variability depends on three conditions; the sea conditions, because when they are bad the catchability is lower, the information accuracy of harvest logbooks and the heterogeneity of *Gelidium sesquipedale* distribution and abundance throughout the harvest zone. To improve logbook data, information on the sea conditions on each harvest day should be included. It is also important that harvesters understand the use of the data collected and understand the necessity for providing accurate records. Managers and scientists have to communicate with harvesters and illustrate how the information obtained from harvest effort data is to be used.

The consistently higher variability of CPUE data of zone 5 suggested higher bottom heterogeneity than in zone 6. Spatial heterogeneity can be minimized if the harvest beds are well located and designated, so that the harvest effort data of logbooks refer to small, more homogeneous, areas. This would also allow the assessment of the spatial distribution of the harvest and its evolution throughout the harvest season, an indirect measure of the spatial variation of resource abundance throughout the harvest zone. The seasonal CPUE is related to the overall abundance of *Gelidium sesquipedale* in the harvest zone. Its highest values were obtained for 1989 in zone 5 and 1999 and 2000 in zone 6 (Fig. 3) indicating highest values of biomass per unit of bottom area.

A large advantage of stock assessment based on harvest effort information, as performed here, is its low cost compared with the expensive evaluation involved in scientific diving. The analysis of the highly informative data of harvest effort is a powerful tool for the management of the *Gelidium sesquipedale* resource in Portugal, which has been undertaken mostly based on in situ assessments of species abundance.

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