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# Temporal Changes in the Harvest of the Brown Algae *Macrocystis pyrifera* (Giant Kelp) along the Mexican Pacific Coast

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## 1. Introduction

*Macrocystis pyrifera* (L.) C. Agardh “Sargazo gigante” is distributed along the west coast of Baja California Peninsula, from the border with the USA to Punta Prieta, Baja California Sur. This kelp forms dense submarine prairies that emerge from the sea covering areas of several hectares or square kilometers. *Macrocystis* has been harvested from Islas Coronado (32° 15' N) to Bahía del Rosario (30° 30' N) in 15 beds for 49 years, from 1956 to 2004. It was exported raw for alginate production. Recently, it has been harvested in smaller quantities to obtain extracts to be used as fertilizer (Casas-Valdez et al., 2003).

The *Macrocystis* seaweed was harvested by specially designed ships that cut the algae at a depth about of 1.2 m and then transported it. The ships “El Capitán” harvested from 1956 to 1966 (storage capacity of 300 t) and “El Sargacero” from 1967 to 2004 (storage capacity of 400 t). The ship operations were the same at all beds and did not change over the study period.

The biomass and standing crop of *Macrocystis* was evaluated in summer 1982 and in an annual cycle in 1985-1986 in their natural distribution (Casas-Valdez et al., 1985; Hernández-Carmona et al., 1989a, 1989b, 1991). The recruitment and effect of nutrient availability during the ENSO event of 1997-1998 at the southern limit of distribution of *Macrocystis* were studied by Lada et al. (1999), Hernández-Carmona et al. (2001) and Edwards & Hernández (2005). The relationship between environmental variables as temperature, upwelling, sea level and wind speed and the catch per unit effort (CPUE) of *Macrocystis* were analyzed by Casas-Valdez et al. (2003). They found an inverse correlation between temperature and harvest and concluded that temperature is the variable that best explained the variations in the *Macrocystis* harvest.

This is the first time that the temporal variability of harvest, effort, and harvest per unit effort (CPUE) as an indicator of the abundance in each of 15 harvested beds of *Macrocystis* has been analyzed.

## 2. Data and methodology

Daily records from 1956 to 1999 were provided by Productos del Pacífico, S. A. de C. V. These contained the information of harvest date, name of the bed, number of trips, and

harvest size (wet weight). Total data were extracted from 3 230 daily records. For the period 1993 to 1999, additional information was obtained of the time of harvest from 638 records. With these data we estimated the monthly, seasonal, and annual values of harvest, effort and harvest per unit of effort for each bed and for the full region. The difference in the storage capacity of the two ships was weighted according with Casas-Valdez et al. (2003). We selected as units of effort: a) the number of trips and b) the time of harvest. The harvest per unit effort (CPUE) (volume of harvest per trip made by each ship or volume of harvest per hour of harvest), was calculated with the equation-

$$\text{CPUE} = C / f \quad (1)$$

Where: C = volume of *Macrocystis* harvested; f = effort

Seasonal harvest, and harvest and effort per category were compared using an ANOVA analysis with the software Statistic 7.0. The significant difference among treatments was determined using the Tuckey test. The relationship between the harvest of *Macrocystis* and the effort was determined through correlation analysis (Anderson, 1972).

### 3. Results

#### 3.1 Harvest, effort, and CPUE in *Macrocystis* beds

*Macrocystis* was harvested from Islas Coronado (32° 15' N) to Bahía del Rosario (30° 30' N) from 1956 to 2004 at 15 beds: Islas Coronados (01), Playas de Tijuana (02), Punta Mezquite (03), Salsipuedes (04), Isla Todos Santos (05), San Miguel y Sauzal (06), Punta Banda (07), Bahía de La Soledad (08), Santo Tomás (09), Punta China (10), Punta San José (11), Punta San Isidro (12), Punta San Telmo (13), Punta San Martín (14) and Bahía del Rosario (15) (Fig. 1). These beds are located at a distance of 1-5 km of the coast.

The harvest of *Macrocystis* increased from 9,900 t in 1956 to 41,500 t in 1976-1977. The average harvest from 1978 to 1982 was 30,000 t, from 1984 to 1997 it was 32,000 t and from 1999 to 2004 was 28,000 t (Fig. 2). In the years 1958, 1983, and 1998 the harvest underwent drastic reductions due the high temperatures presented due to ENSO phenomena. The historical series of CPUE accordingly shows considerable decreases during 1958, 1983, and 1998. In all the other years it was almost a constant level at an average of 342 t/ trip.

The historical series of harvest and effort of the 15 beds of *Macrocystis* (Figs. 3, 4, and 5) show that there is ample variability among them. For example, the Punta Mezquite (03) bed was harvested for 40 years, with an effort of 741 trips (Fig. 6) and a total harvest of 257,000 t. The Punta Banda (07) bed, however, was only harvested for 5 years, with an effort of 5 trips (Fig. 6) and a total harvest of 1,800 t.

Considering the average harvest and the effort applied during 49 years the *Macrocystis* beds were grouped into three categories; I) with an average harvest of 2,160 t (1,800 – 76,450 t) and an effort of 6 trips/ year (01, 02, 05, 06, 07, 11, 12, 13, 14 and 15); II) with an average harvest of 3,600 t (90,800 – 176,150 t) and an effort of 12 trips/ year (04, 08, 09 and 10); III) with an average harvest of 6,400 t (257,000 t) and an effort of 19 trips/ year (03). There are significant differences ( $P < 0.05$ ) among categories. The variation of the CPUE of *Macrocystis* beds is shown in figures 7, 8 and 9. The CPUE was more stable in the beds where more effort was used (03, 04, 08, 09 and 10).

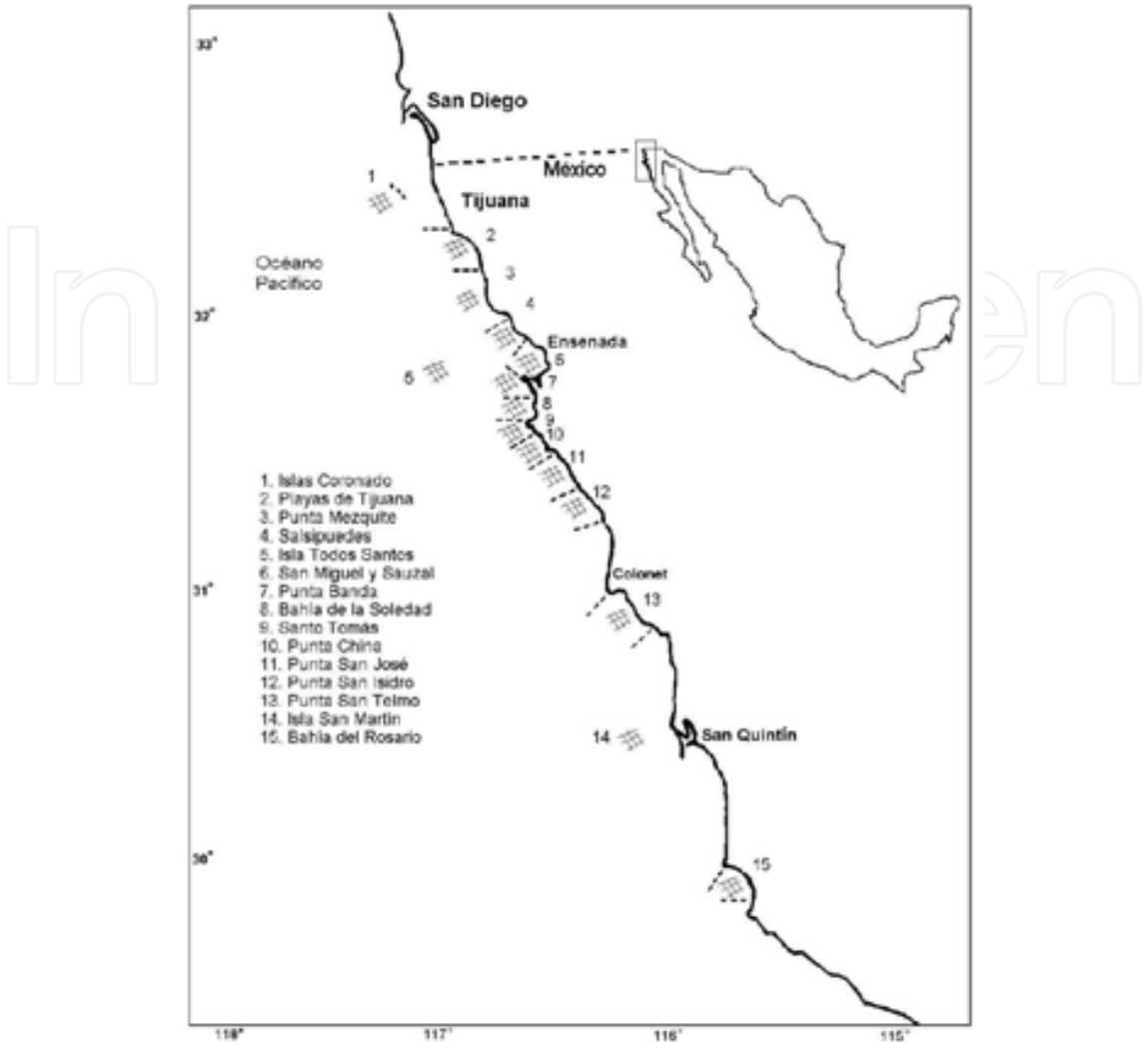


Fig. 1. Distribution of *Macrocystis pyrifera* beds harvested off the Baja California Peninsula (Taken from Casas-Valdez et al., 2003).

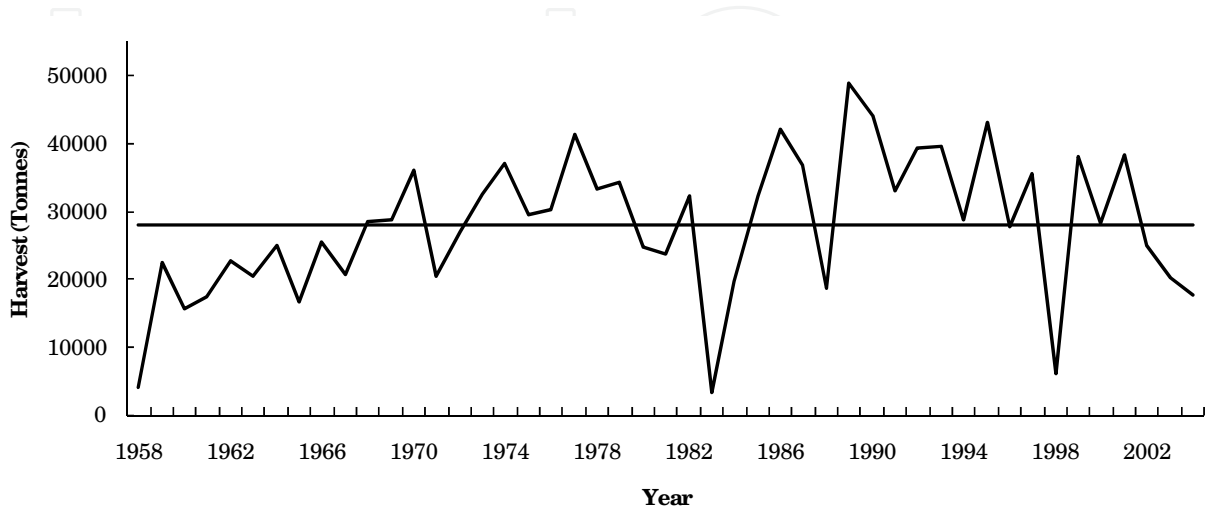


Fig. 2. Data series of harvest volume of *Macrocystis pyrifera*.

### 3.2 Seasonal variation

The harvest of *Macrocystis* off the Baja California Peninsula shows a seasonal pattern with minimum values in winter, and the maximum during spring and summer, then decreasing in autumn (Fig. 10). The spring and summer harvests were greater ( $P < 0.05$ ) than winter and autumn, and the harvest of winter was the lowest ( $P < 0.05$ ). In general the harvest of all beds had the same pattern. In the beds at Punta Mezquite (03), Salsipuedes (04), and Bahía de la Soledad (08), which were more frequently exploited, this pattern is evident, and less so the beds less harvested, such as Playas de Tijuana (02), Isla Todos Santos (05), and San Isidro (12). A similar behavior was found when the harvest obtained per hour of ship harvest (CPUE) for 1993 – 1999 was analyzed. The highest harvest/ hour was during May to August (75 t/ hour). These values were significantly different ( $P < 0.05$ ) to both periods: February to April (62 t/ hour) and September to December (54 t/ hour), which were lower (Fig. 11).

### 3.3 Relation harvest-effort

During 1956 to 1999, the harvest of *Macrocystis* increased as a function of the level of effort (number of trips) ( $r = 0.98$ , Fig. 12) and similarly when the effort was measured as number of hours of ship harvest ( $r = 0.85$ ) for 1993 –to 1999 (Fig. 13).

## 4. Discussion

From 1958 to 2004, the average harvest of *Macrocystis* was 26,000 t, which was about 50% of the standing crop estimated by Casas-Valdez et al. (1985) and Hernández et al. (1989a, 1989b, 1991), who evaluated the biomass and standing crop of *Macrocystis* using aerial photography and field work along the area of the distribution of this kelp. From Islas Coronado to Bahía del Rosario they estimated a standing crop of 40,000 t in summer 1985 and 63,000 t in summer 1986. This species of seaweed has a high growth rate (13 - 21 cm/ day) (Hernández, 1996) and its regeneration rate is high.

The lowest harvest and effort recorded in category I can be related to: a) the harvest being suspended in beds 11 (1978), 06 (1985), 07 (1984), 02 (1991), and 01 (1993), b) the long distance from the beds to the base port, bed 12 (12 h 20 min), 13 (13 h), 14 (16,5 h), and 15 (20 h). The highest harvest and effort recorded in category III can be related to a) a high productivity of the bed and, b) the short distance from the bed to the base port (5 h). In relation to the previous information, Roberto Marcos (com. pers.) noted that the quantity of effort used at each bed depended on the productivity of the bed and its cost of operation, which are related principally to the distance that the ship must run from the base port to the bed. Guzmán et al. (1971) and Corona (1985) mention that the more productive beds for 1956 – 1968 and 1974 – 1985 were the beds 03, 04, 08, 09, and 10 that are in categories II and III of this study. The largest harvest of *Macrocystis* was in spring and summer and the lowest in winter.

Along the northwest coast of the Baja California Peninsula the greatest upwellings are during spring and summer (Casas-Valdez, 2001) and have high nutrient concentrations and lower temperatures (Lynn & Sympson, 1987; Parés & O'Brien, 1989) that favor the development of *Macrocystis* fronds (Tegner & Dayton, 1987; Tegner et al., 1996; Lada et al., 1999). Growth studies *in situ* showed that the lower temperatures of spring enhance the growth rate of *Macrocystis* (González et al., 1991) and also the increase of nutrients (Zimmerman & Kremer, 1986). Casas-Valdez et al. (1985) and Hernández-Carmona et al. (1989a, 1989b, 1991) evaluated the biomass and standing crop of *Macrocystis* along their natural distribution and found the largest surface and biomass of the beds in spring (45,000 t) and summer (63,000 t). They noted that these values were three times greater than those in winter (14,000).

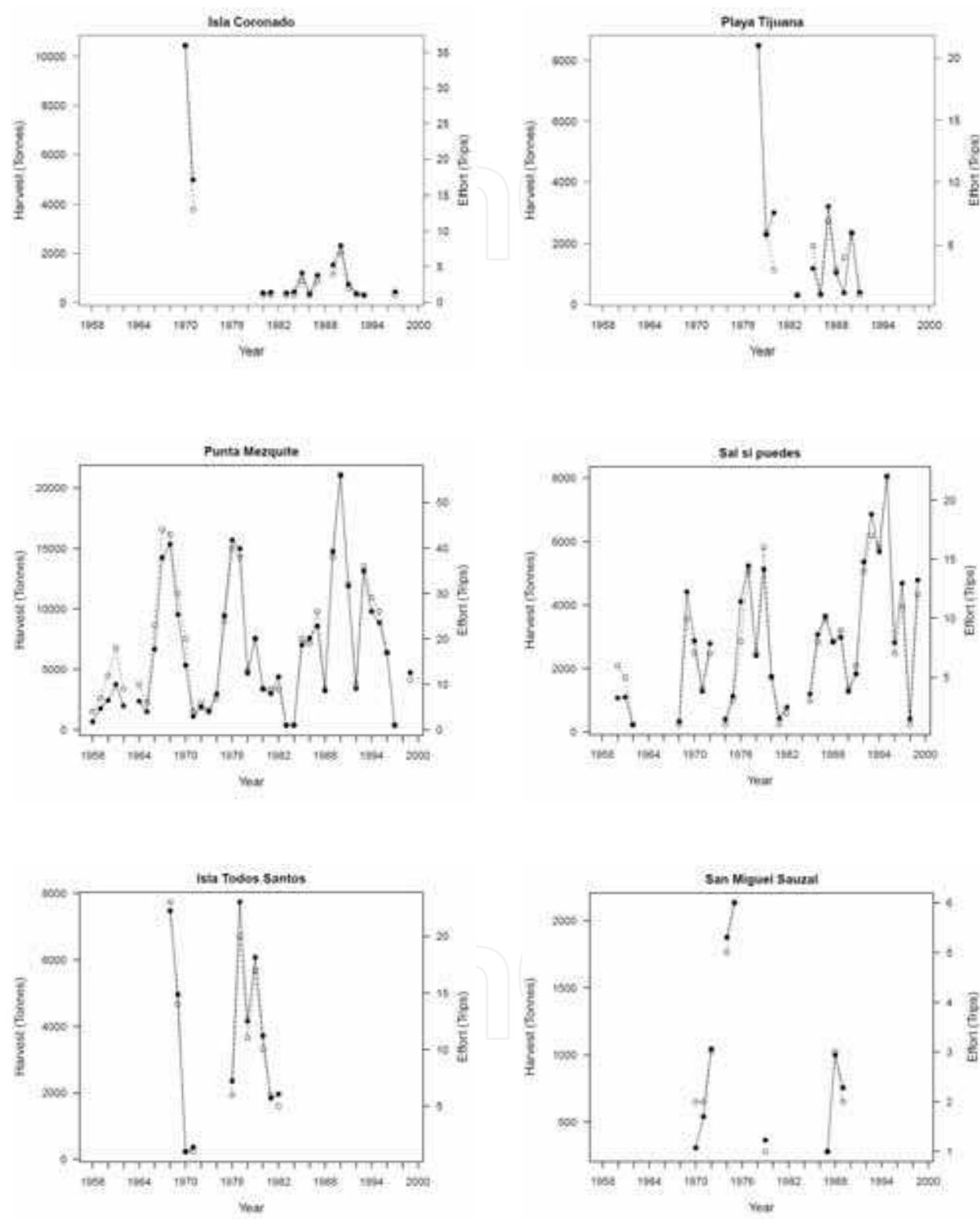


Fig. 3. Data series of harvest and effort of the *Macrocystis pyrifera* beds: Islas Coronados, Playas de Tijuana, Punta Mezquite, Salsipuedes, Isla Todos Santos and San Miguel y El Sauzal. Harvest —●—, effort -○-.



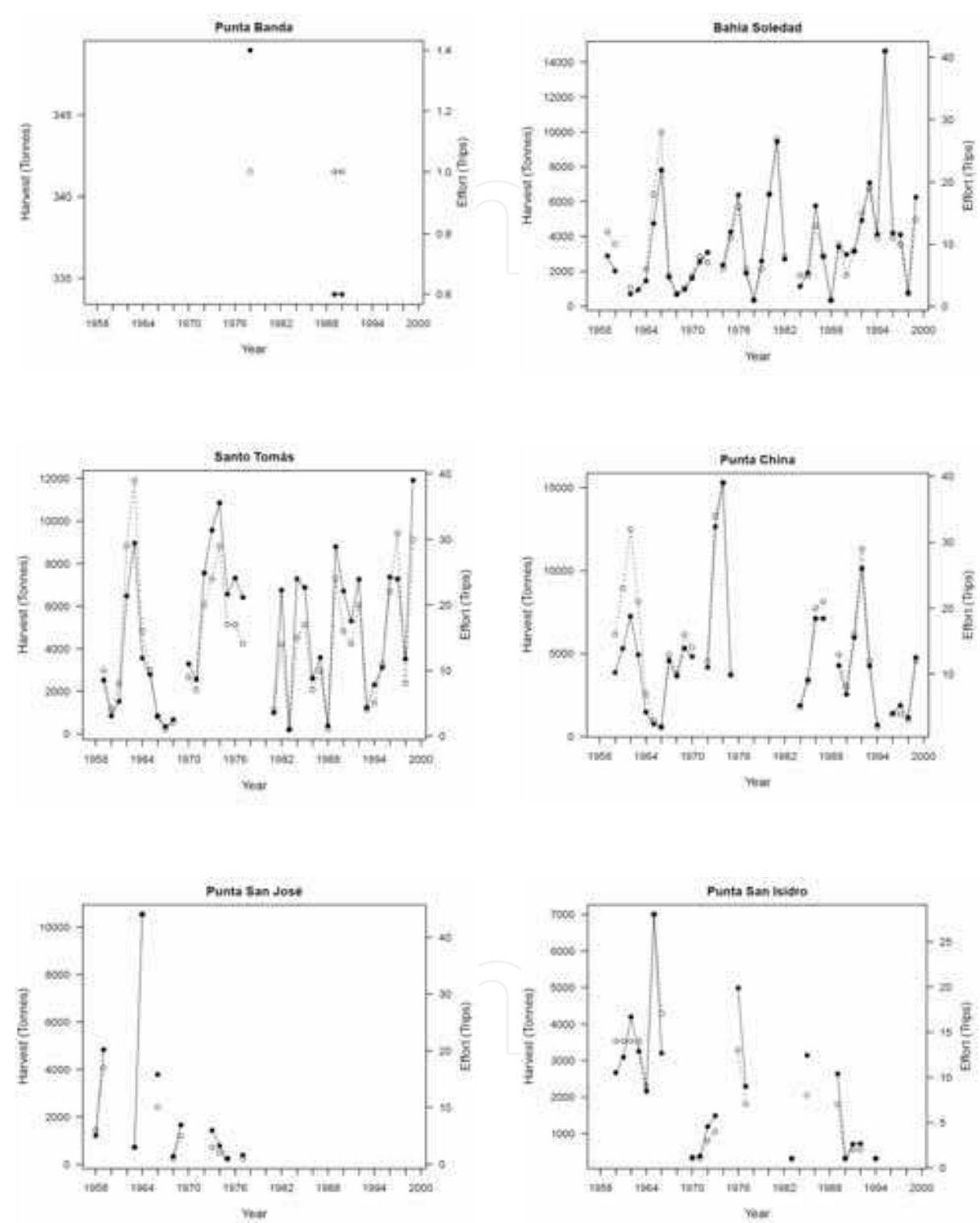


Fig. 4. Data series of harvest and effort of the *Macrocyctis pyrifera* beds: Punta Banda, Bahía de la Soledad, Santo Tomás, Punta China, Punta San José and Punta San Isidro. Harvest —●—, effort -○-.

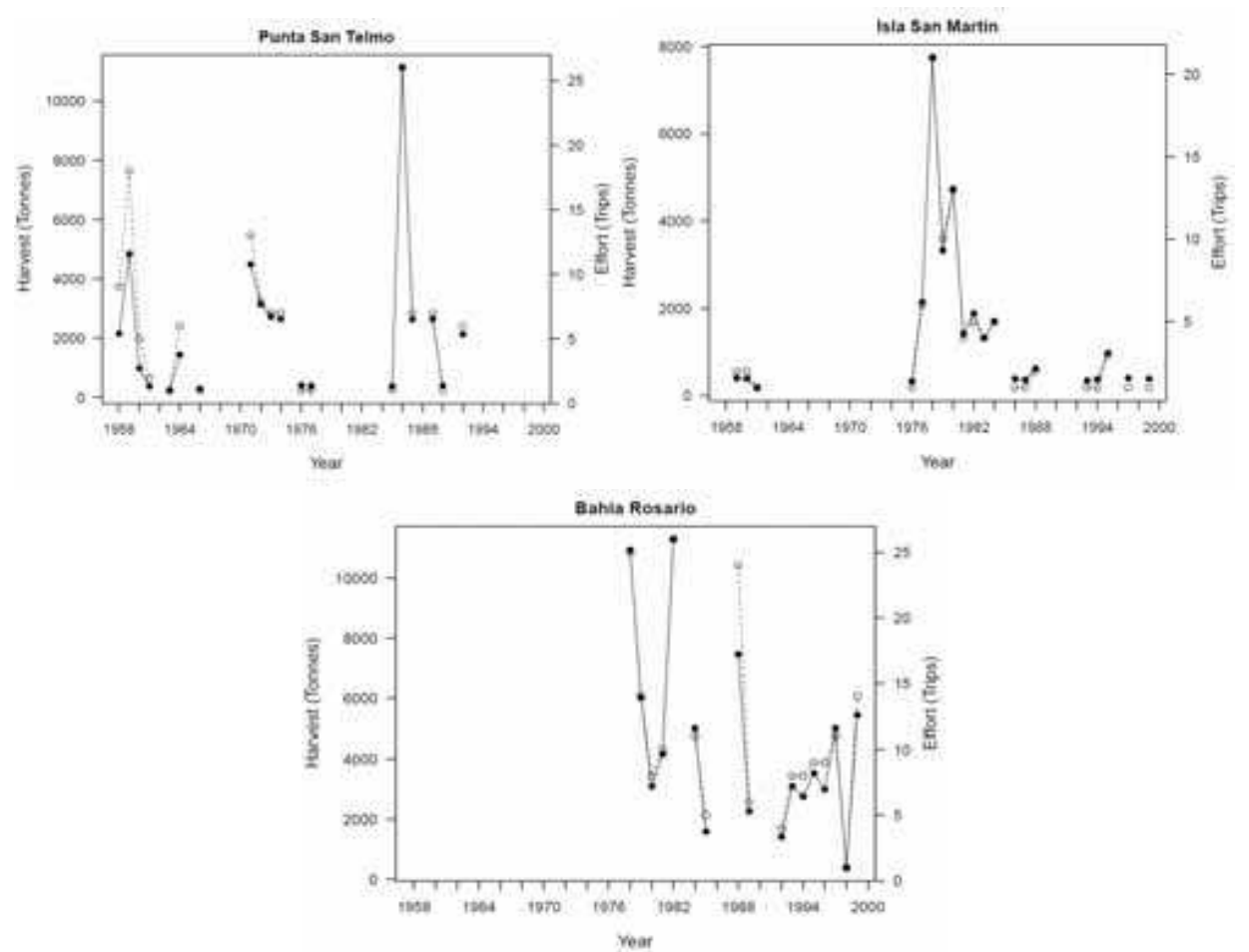


Fig. 5. Data series of harvest and effort of the *Macrocystis pyrifera* beds: Punta San Telmo, Isla San Martín and Bahía del Rosario. Harvest —●—, effort -○-.

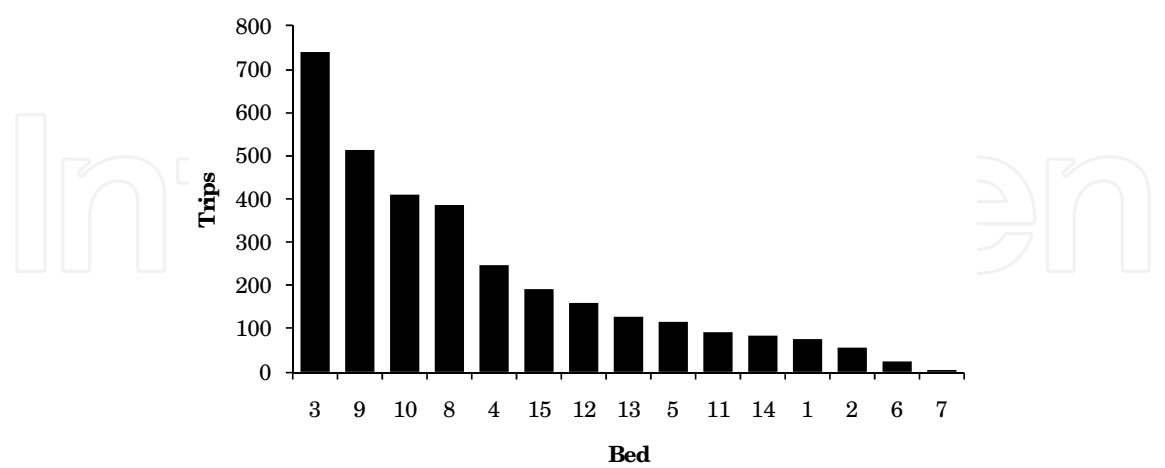


Fig. 6. Number total of trips in the beds: (01) Islas Coronados, (02) Playas de Tijuana, (03) Punta Mezquite, (04) Salsipuedes, (05) Isla Todos Santos, (06) San Miguel and El Sauzal, (07) Punta Banda, (08) Bahía de la Soledad, (09) Santo Tomás, (10) Punta China, (11) Punta San José, (12) Punta San Isidro, (13) Punta San Telmo, (14) Isla San Martín and (15) Bahía del Rosario.



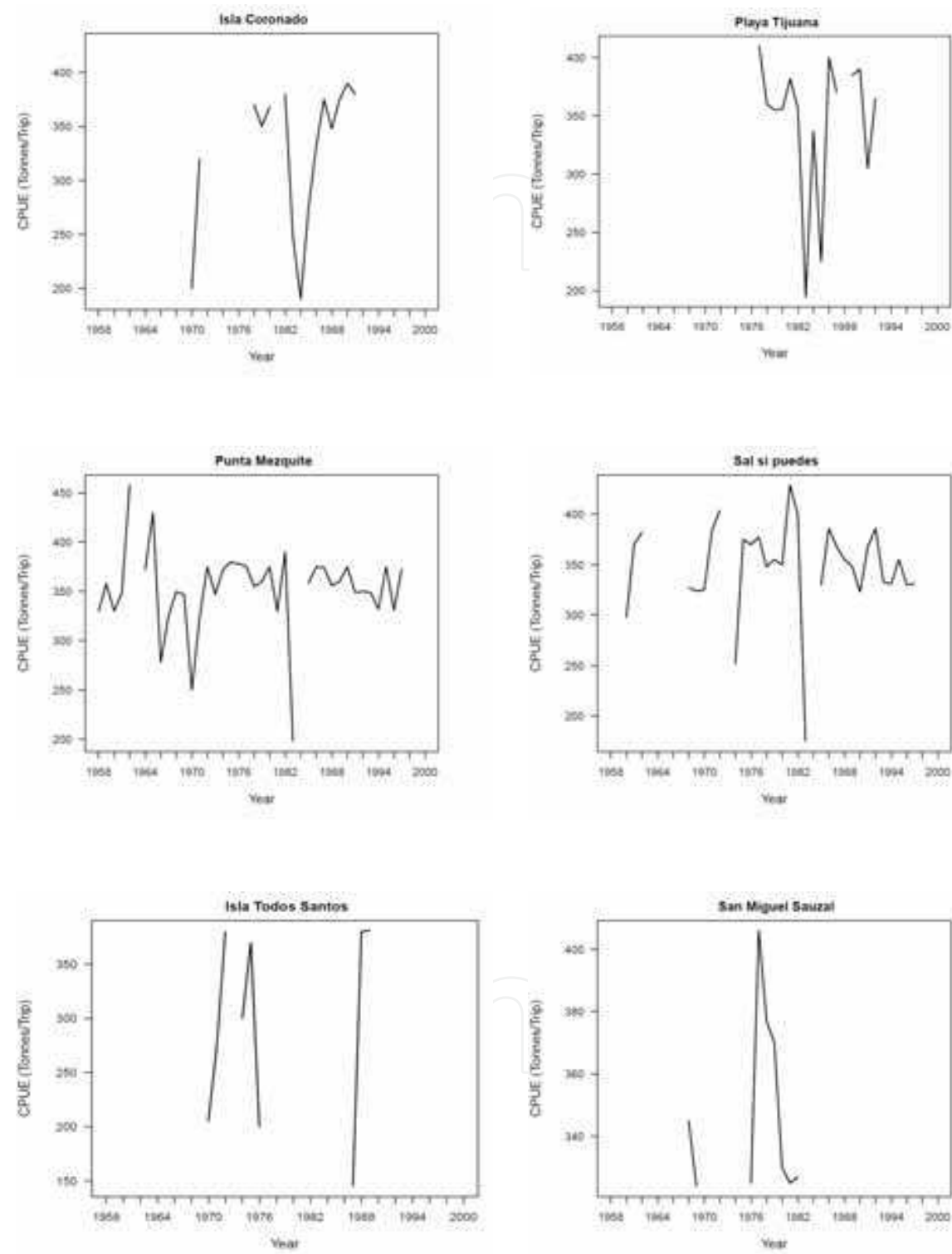


Fig. 7. Data series of harvest per unit effort (CPUE) of the *Macrocystis pyrifera* beds: Islas Coronados, Playas de Tijuana, Punta Mezquite, Salsipuedes, Isla Todos Santos and San Miguel y El Sauzal.

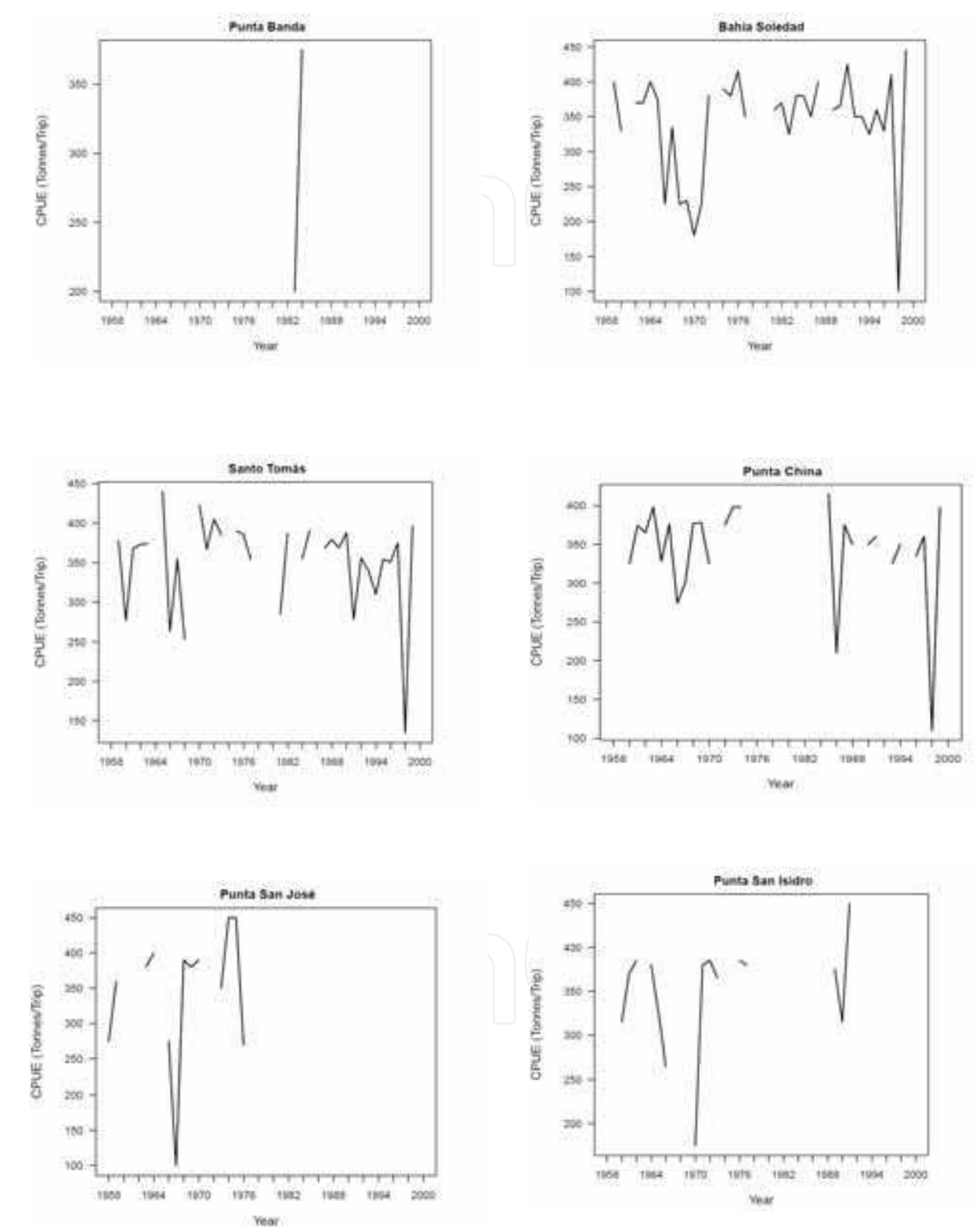


Fig. 8. Data series of harvest per unit effort (CPUE) of the *Macrocystis pyrifera* beds: Punta Banda, Bahía de la Soledad, Santo Tomás, Punta China, Punta San José and Punta San Isidro.

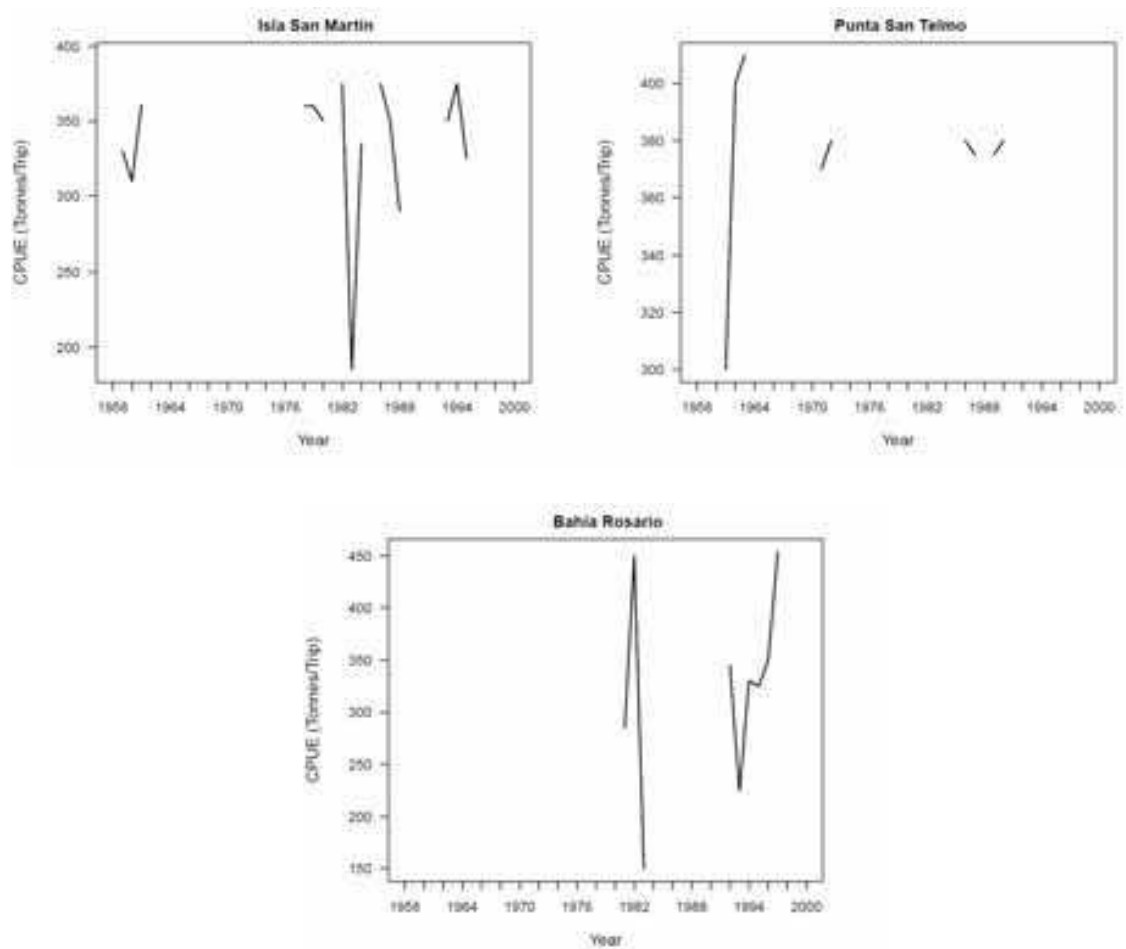


Fig. 9. Data series of harvest and effort of the *Macrocystis pyrifera* beds: Punta San Telmo, Isla San Martín and Bahía del Rosario.

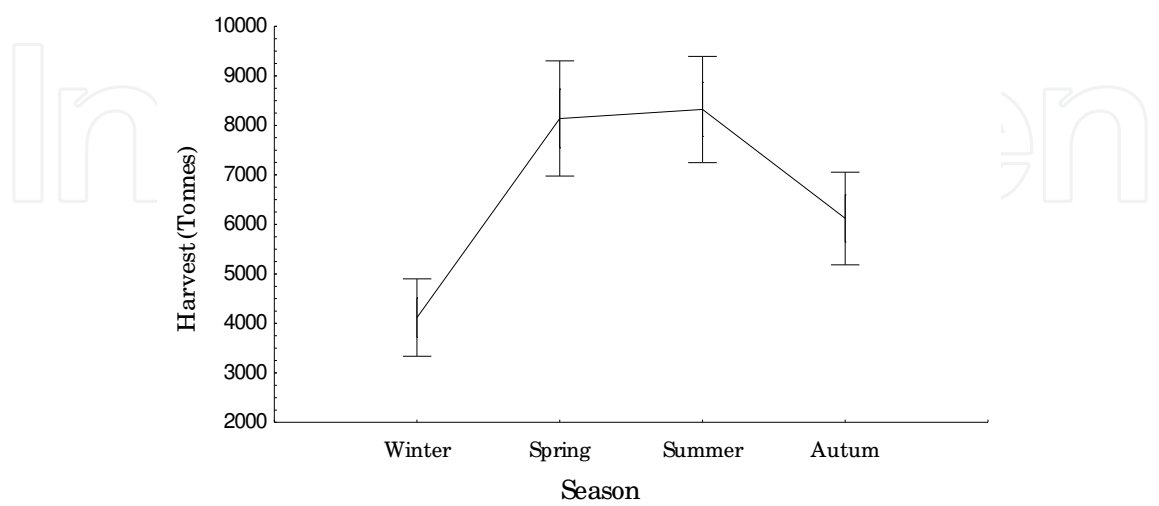


Fig. 10. Seasonal variation of the harvest of *Macrocystis pyrifera* in Baja California Peninsula.  $\pm 2$  SD.

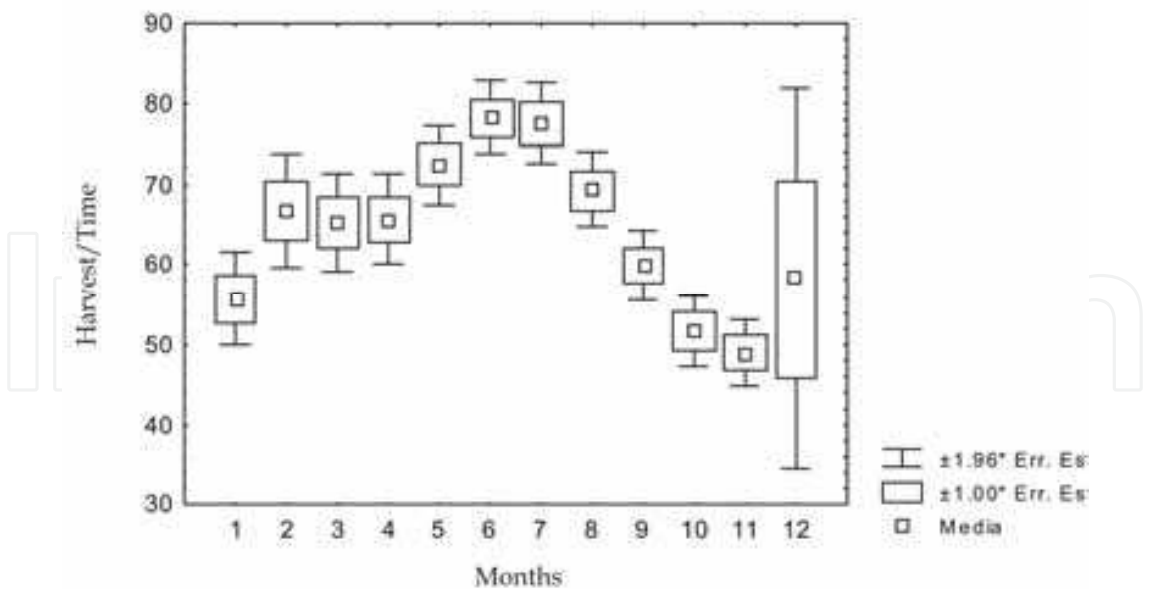


Fig. 11. Monthly average harvest per hour of *Macrocystis pyrifera* in the Baja California Peninsula for the period of 1993-1999.

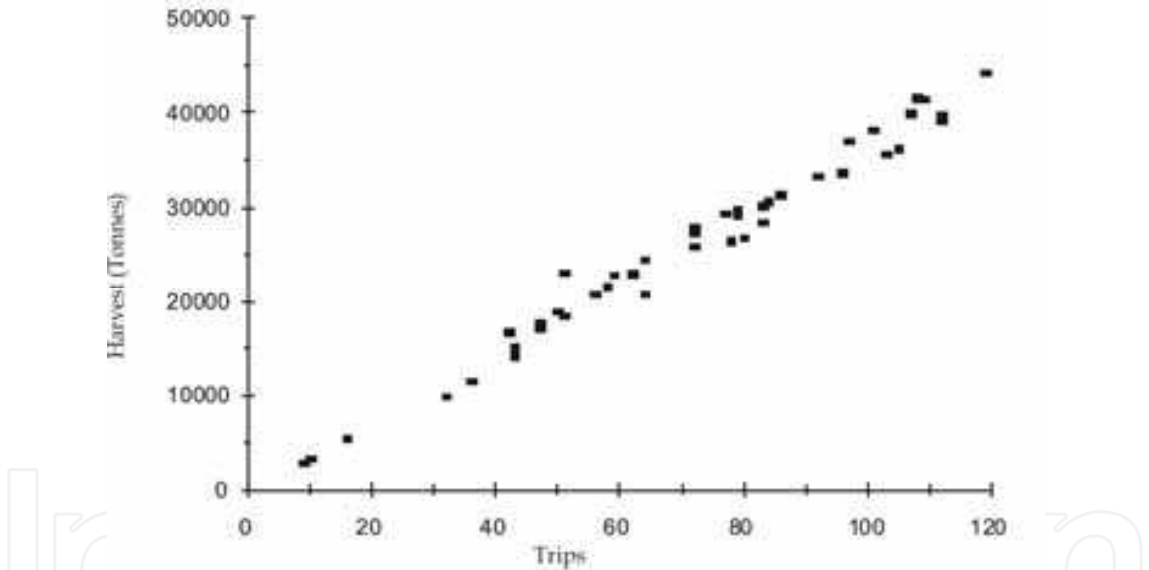


Fig. 12. Relationship of the harvest and effort (number of trips) of *Macrocystis pyrifera* for the period of 1956-1999.

The CPUE was used as indicator of abundance for *Gelidium robustum* a red seaweed that is harvested along in the west coast of the Baja California Peninsula from 1956 to the present. The unit of effort selected for this fishery was the fishing equipment (a boat with three fishermen) and the CPUE was expressed as harvest/ boat (Casas-Valdez et al., 2001). They used the CPUE to determine the relationship of the abundance of *Gelidium* with both temperature and upwelling. As an indicator of the abundance of *Macrocystis*, Tegner et al. (1996) compared data on the maximum canopy of the kelp forest and size of the annual harvest of *Macrocystis* for California, and they chose harvest size as the most useful data to relate to environmental variables. They pointed out that harvest size was a reflection of

changes in consumer demand, harvest productivity, and natural disturbances. They also noted that this variable has the advantage of integrating growth over a long period and has less subjectivity in its measurement.

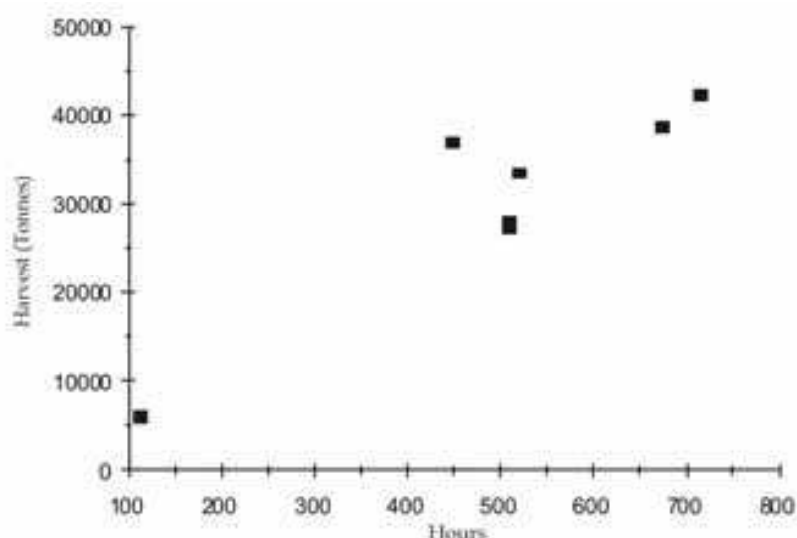


Fig. 13. Relationship of the harvest and effort (number of hours) of *Macrocystis pyrifera* for the period of 1956-1999.

In our study, we considered that the CPUE shows the changes in the abundance of *Macrocystis* better than only the harvest, because the size of the harvest varies according to the amount of effort used and not only as a function of the abundance. Furthermore, the use of the CPUE is cheaper than the use of aerial photography and field work to determine the variations in the abundance of this resource. Casas-Valdez et al. (2003) mentioned that the harvest/ trip is a reasonable indicator of the *Macrocystis* abundance, because about 60% of the alga biomass is present in the surface canopy (North, 1968), and almost 95% of its production takes place in the first meter of the top of the water column, and the kelp is harvested at a maximum depth of 1.2 m. Furthermore the ship operations were the same at all beds and did not change over the study period. We considered that the harvest/ hour is a better indicator.

The surplus production models of Schaefer and Fox were used to assess the fishery condition of *Gelidium* off the Baja California Peninsula from 1985 to 1997. The results have shown that the resource is not overexploited (Casas-Valdez et al., 2005). In this study we tried to use these surplus models for the data of *Macrocystis*, but the fit was not satisfactory. This occurred because an increased effort produced increased harvest. To fit these models, it is necessary to count, along with the catch, effort, and CPUE data, an ample range of fishing effort levels, preferably including those that correspond to the level of overexploitation in the curve (IATTC, 1999). The linear relation (correlation) found between the harvest and the effort used for the *Macrocystis* fishery means that the fishery was in the eumetric growth segment of the curve of the Schaefer model and therefore it is possible to conclude that there have not been negative effects of the harvest on the resource. It is considered that the effort has not been increased, due to the fact that the demand for *Macrocystis* has not been increased either. In fact, the harvest drastically decreased in 2005, when the principal company that was buying this kelp as raw material for the alginate production ceased buying it (Roberto Marcos com. pers.).

## 5. Conclusions

The *Macrocystis* fishery along the Mexican Pacific coast did not show signals of over exploitation due to increases in the effort corresponding to increases in the harvest, and the CPUE has been maintained almost constant since the beginning of the harvesting of this resource until now (2004), with the exception of the years when “El Niño” event was present.

Along the northwest coast of the Baja California Peninsula, the highest harvest of *Macrocystis* was found in spring and summer, when the greatest upwellings occur in agreement with high nutrient concentrations and lower temperatures.

The harvest per unit of effort (CPUE) was more stable in the beds where more effort was used, as in the beds at Punta Mezquite, Salsipuedes, Bahía de La Soledad, Santo Tomás and Punta China, whereas in the beds where less effort was used the CPUE was more variable.

## 6. Acknowledgment

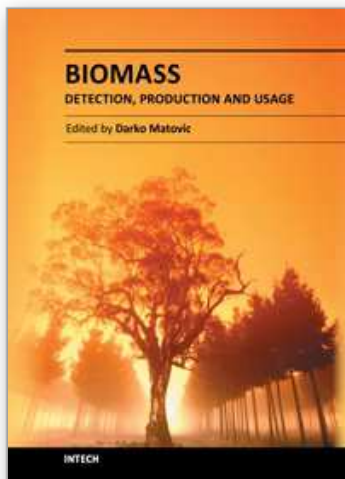
Thanks to Productos del Pacifico, S. A. de C. V. for providing the data of harvest of *Macrocystis*. We really appreciate the adviser of Roberto Marcos Ramírez. Thanks to Dr. Ellis Glazier for editing this English-language text. Margarita Casas Valdez and Daniel Lluch Belda are fellows of COFAA-IPN and EDI-IPN.

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## **Biomass - Detection, Production and Usage**

Edited by Dr. Darko Matovic

ISBN 978-953-307-492-4

Hard cover, 496 pages

**Publisher** InTech

**Published online** 09, September, 2011

**Published in print edition** September, 2011

Biomass has been an intimate companion of humans from the dawn of civilization to the present. Its use as food, energy source, body cover and as construction material established the key areas of biomass usage that extend to this day. Given the complexities of biomass as a source of multiple end products, this volume sheds new light to the whole spectrum of biomass related topics by highlighting the new and reviewing the existing methods of its detection, production and usage. We hope that the readers will find valuable information and exciting new material in its chapters.

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