Photo: Diego Ruiz

# A revised strategy for the monitoring and management of the Galapagos sea cucumber

**Anna Schuhbauer[1], Matthias Wolff[1] and Mauricio Castrejón[2]**

[1]Charles Darwin Foundation (CDF), [2]World Wildlife Fund (WWF)

## Introduction

The Galapagos sea cucumber fishery began in the early 1990s with catches increasing annually until a peak period from 1999 to 2005. During this peak period nearly 30 million sea cucumbers were harvested legally within the Galapagos Marine Reserve (GMR), corresponding to a total fresh weight of over 8000 tons (CDF/GNP Fisheries Reports). Catches peaked in the year 2002, with over 8.3 million individuals harvested (Figure 1). Following 2002, the harvest continued to decrease as a result of permanent overfishing due to factors such as overcapacity of the fishing fleet, a "race for fish" situation - a worldwide phenomena caused by a total allowable catch for all fishermen versus individual quotas for each fishermen making them fish as much as they can in as little time as possible - and a reactive instead of proactive fisheries management system. In addition, the determination of an annual quota was not based on a scientific study; rather it was negotiated with the fishermen and was therefore largely based on their demands.

In 2008, for the first time, a limit reference point (LRP) of 11 individuals/100 $m^2$ in the principal fishing zone west of Isabela Island was established - as derived from the pre-fishery monitoring - to determine if the fishing season would be opened or not. The use of this LRP caused two problems. First, instead of using stock size as the basis for the LRP, mean densities based on pre-fishery monitoring in the principal fishing zone (western Isabela) were used as the condition for opening the fishery. This motivated fishermen, who participated in the monitoring, to focus on areas where densities had traditionally always been high. The results unfortunately did not represent the overall mean density in all fishing areas. The second problem was that once the fishery was opened, fishermen harvested all sea cucumbers above the minimum landing size (20 cm total length) within their quota (when applied) and economic limits. This led to the post-fishery stock being extremely small without the potential to rebuild prior to the next year's fishing season. When sea cucumber densities are too small, fertilization is not possible and the stock cannot recover.

This study evaluated the monitoring and management strategy of the sea cucumber fishery during the past 10 years and aimed to estimate the stock size

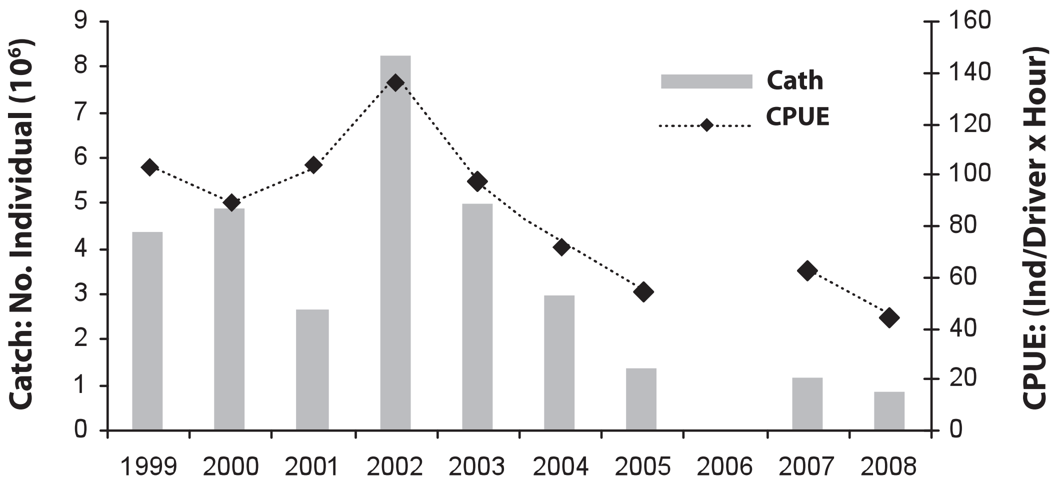



**Figure 1.** Annual catch in number of individuals and Catch per Unit of Effort (ind/diver*hour) from 1999-2008 (2006 season was closed). Source: CDF Fisheries Reports.

and to optimize the way in which the annual harvest quota is determined. In recent years, fishermen have argued that sea cucumbers may be more abundant in deeper, less fished waters, thus providing the needed stock reserves to counteract heavy fishing in the shallower waters. Therefore, we compared mean densities in shallow areas (< 15 m) with those in deeper waters (> 15 m). The results of the 2009 monitoring season were compared with those from the past ten years in order to demonstrate density and size structure trends, specifically the proportion of specimens smaller than 20 cm in the population. This trend in size structure should be indicative of recruitment strength in previous years.

## Methods

### Area estimates, transect numbers, and density estimates

Macrozones were defined based on historical and current major fishing areas, identified through onboard fisheries observations from 1999 to 2008, gathered by the Galapagos National Park (GNP) and the Charles Darwin Foundation (CDF). The zones were then delimited based on bathymetric data compiled by Chadwick (1994), which were interpolated using ArcGIS. The outer boundary was set at the -30 m isobath, based on historical data indicating that it is the maximum depth at which diving for sea cucumbers is carried out (CDF Fisheries Reports). With the isobath line as the outer and the coastline as the inner boundary, the area of each macrozone ($km^2$) was mapped. Of the total macrozone area, the suitable habitat for sea cucumbers and therefore the effective fishing area was estimated at approximately 50%, given that approximately 30% has unsuitable sandy bottoms and another 20% is either intertidal waters that are too shallow (< 5 m) or uninhabitable steep slopes.

To calculate the number of transects required to represent each macrozone, we reviewed means and standard deviations of stock densities from previous surveys. Based on this, the minimum number of replicates (transects) needed to achieve a precision of ±25% was estimated using the following formula:

$$n = \left(t_{(n-1)} * \frac{SD}{0.25 * Av}\right)^2$$

where n = minimum number of replicates required to achieve a precision of ±25% around our estimate of mean density; t = value of the t distribution (student's t-test) for $p < 0.05$; Av = annual average sea cucumber density per macrozone, and SD its standard deviation.

The number of replicates required for the different macrozones varied depending upon differences in spatial distribution and stock density, with more replicates needed in areas with greater patchiness and fewer in zones where the population appears more evenly distributed.

A circular transect (radius of 5.6 m, area of 100 $m^2$), proven to be effective in previous studies, was used. Transects were evenly distributed over the two depth strata (<15 m and >15 m). The mean number of sea cucumbers per $m^2$ within each macrozone was extrapolated for the entire macrozone and then the stock sizes of all macrozones were summed to determine the stock size of the entire effective fishing area.

Since the density values of each macrozone were not normally distributed, a bootstrap resampling routine (Efron, 1981) was applied. This consisted of a random resampling (1000x) of the data matrix for each macrozone. This yielded 1000 normally distributed mean density values and allowed for the computation of the standard deviation and coefficient of variation around the mean. To test for depth differences in sea cucumber densities, all measurements taken in each depth stratum (5-15 m and 15-25 m, respectively) were considered for the calculation of overall means per depth strata. The resulting mean densities were bootstrapped for each stratum and compared using a t-test of means. For comparative purposes we also applied a non-parametric Mann-Whitney U test for the medians.

### Calculating the catch quota

Under conditions of sustainable exploitation, annual stock production is balanced by the sum of Fisheries Mortality (F) and Natural Mortality (M), called Total Mortality (Z). Cadima (in Troadec, 1977) proposed the following formula to attain maximum sustainable yield from an already fished resource:

Maximum Sustainable Yield (Quota) = $0.5 * Z * B$

where B = current stock biomass.

This formula was shown not to be applicable if $F > M$; however, and even in cases when $F = M$ (at an exploitation rate of 50%; $E = F/Z = 0.5$), a stock may be overfished as was shown by Garcia and LeReste (1980). Following this reasoning, we chose a more precautionary rate of 30% or $E = 0.3$, when applying the above formula. With our value for the Natural Mortality at 17% ($M = 0.17$) based on Hearn *et al.* (2005), the Fishery Mortality was calculated as follows: $F = 0.073$. By inserting the resulting Total Mortality value ($Z = F + M = 0.243$) in Cadima's formula we arrived at a quota estimate of:

Quota = $0.5 * 0.243 * B = 0.122 * B$

Therefore, the annual quota or total allowable catch (TAC) proposed is 12.2% of the standing stock.

## Results

### Estimates of macrozone areas and number of transects per macrozone

The distribution of sea cucumber fishing activities in the archipelago from 1999 to 2008 was determined from data collected by onboard fisheries observers (Figure 2). These data were used to define the

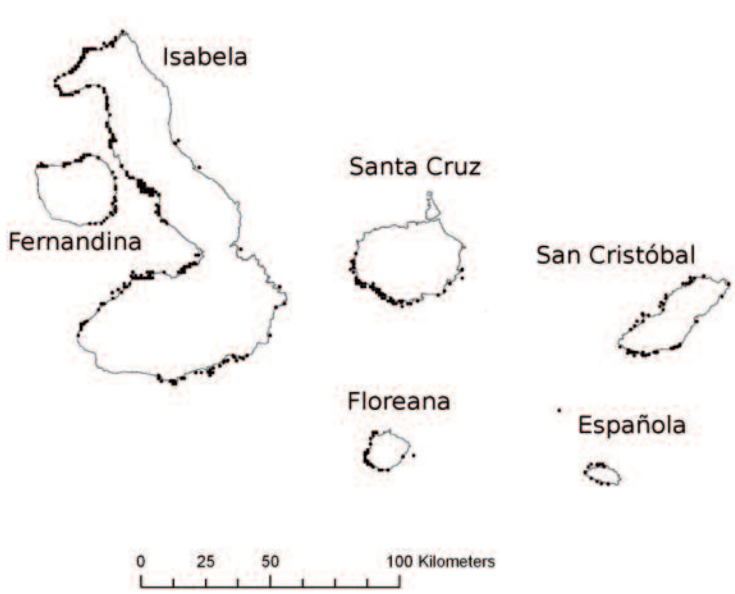
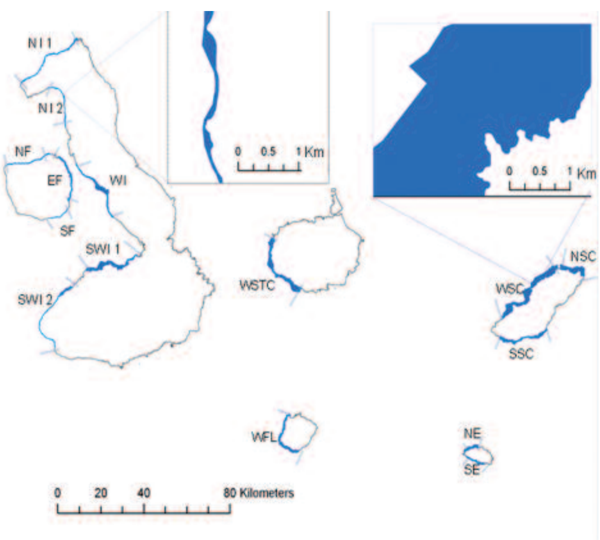



**Figure 2.** Sea cucumber fishing sites in Galapagos assembled from geographical referenced data from onboard and landing site monitoring (CDF and GNP data bases, 1999-2008).

macrozones (Figure 3). To adequately represent each of these macrozones, the number of transects required to fulfill a 25% precision limit was calculated for each one.

The estimated size of the effective fishing area, which represents 50% of all of the macrozones, is 125 $km^2$ (Figure 3). San Cristóbal has the largest fishing area (52 $km^2$), followed by Isabela (33 $km^2$) and Santa Cruz (20 $km^2$). Floreana, Española, and Fernandina combined represent 20 $km^2$. It is interesting to see that replicate numbers vary greatly between zones, with Española requiring the highest number per area (49/5 $km^2$), while Santa Cruz requires only 31 transects in 20 $km^2$ (Table 1).




| Code | Macrozone | Effective fishing area ($km^2$)* |
|---|---|---|
| NI 1 | North Isabela 1 | 3.6 |
| NI 2 | North Isabela 2 | 1.6 |
| WI | West Isabela | 10.3 |
| SWI 1 | Southwest Isabela 1 | 13.3 |
| SWI 2 | Southwest Isabela 2 | 4.0 |
| NF | North Fernandina | 1.5 |
| EF | East Fernandina | 4.5 |
| SF | South Fernandina | 8.5 |
| WSTC | West Santa Cruz | 20.4 |
| WFL | West Floreana | 0.3 |
| WSC | West San Cristóbal | 31.8 |
| NSC | North San Cristóbal | 10.5 |
| SSC | South San Cristóbal | 9.3 |
| NE | North Española | 3.0 |
| SE | South Española | 2.1 |
| | Total | 125 |

*50% of the total macrozone area

**Figure 3.** Macrozones identified based on the major fishing sites and their effective fishing area (50% of total macrozone area) in $km^2$.

**Table 1.** Mean and maximum density values (ind/100 $m^2$) of all macrozones and islands with the number of transects planned and carried out, standard deviation (SD), and coefficient of variation (CV).

| Island | Macrozone (code) | No. transects planned | No. transects completed | Mean density | Maximum density | SD | CV (%) |
|---|---|---|---|---|---|---|---|
| Isabela | NI1 | 25 | 10 | 2.8 | 7 | 0.7 | 25.00 |
| | NI2 | 19 | 21 | 3.6 | 19 | 0.9 | 25.00 |
| | WI | 55 | 40 | 3.7 | 27 | 0.8 | 21.62 |
| | SWI1 | 57 | 24 | 3.6 | 17 | 0.9 | 25.00 |
| | SWI2 | 23 | 30 | 2.2 | 14 | 0.6 | 27.27 |
| | **combined** | **179** | **125** | **3.3** | **27** | **0.4** | **11.59** |
| Fernandina | NF | 10 | 11 | 1.0 | 8 | 0.7 | 70.00 |
| | EF | 31 | 20 | 3.5 | 16 | 0.9 | 25.71 |
| | SF | 8 | 4 | 1.6 | 6 | 1.3 | 81.25 |
| | **combined** | **49** | **35** | **2.5** | **16** | **0.6** | **24.90** |
| **Santa Cruz** | **WSTC** | **31** | **25** | **4.8** | **23** | **1.1** | **22.82** |
| **Floreana** | **WFL** | **32** | **26** | **2.7** | **13** | **0.6** | **22.14** |
| San Cristóbal | NSC | 14 | 5 | 2.4 | 8 | 1.4 | 58.33 |
| | WSC | 47 | 56 | 4.8 | 42 | 0.9 | 18.75 |
| | SSC | 58 | 36 | 6.1 | 38 | 1.2 | 19.67 |
| | **combined** | **119** | **97** | **5.1** | **42** | **0.7** | **13.26** |
| Española | NE | 28 | 12 | 4.7 | 11 | 0.9 | 19.15 |
| | SE | 21 | 27 | 4.9 | 11 | 0.6 | 12.24 |
| | **combined** | **49** | **39** | **4.9** | **11** | **0.5** | **9.67** |
| **All Islands** | **combined** | **459** | **347** | **3.9** | **42** | **0.3** | **6.81** |

The population monitoring was carried out in the last two weeks of May 2009 by fishermen, and GNP and CDF staff. The work was coordinated and financed primarily by the GNP and WWF. Due to insufficient funds, fewer transects were carried out than originally planned.

## Densities and catch quota for 2009

Mean density of sea cucumbers for western Isabela (3.28 ± 0.38 ind/100 $m^2$) was far below the critical value established for opening the fishery (11/100 $m^2$). Based on these results it was recommended not to open the fishery for the year 2009, which was later accepted by the co-management body, the Interinstitutional Management Authority (IMA).

Following our new approach, the fishing quota or total allowable catch (TAC) for the entire archipelago for the 2009 fishing season would have been 598,938 individuals, based on the stock size (4.9 million individuals) derived from the overall mean density (3.9 ind/100 $m^2$) and our combined area estimate (125 $km^2$).

Based on the pre-fishery monitoring data from 1999-2009 for each island, the mean densities and the proportion of small (< 20 cm) sea cucumbers in the samples show general trends over the past 10 years (Figure 4). In general, sea cucumber densities in Galapagos have decreased since 2002. Floreana, Isabela, and Fernandina show a steady decrease in density over recent years, while Santa Cruz has remained relatively constant. It is interesting to note that the density value for San Cristóbal in 2009 was the second highest density value recorded there since 1999. The proportion of juveniles (recruits) in the stock has steadily decreased for the western islands, Isabela and Fernandina, and in 2009 was the lowest ever recorded in Española and Floreana. Santa Cruz and San Cristóbal reveal a slight increase in recruits over the last three years.

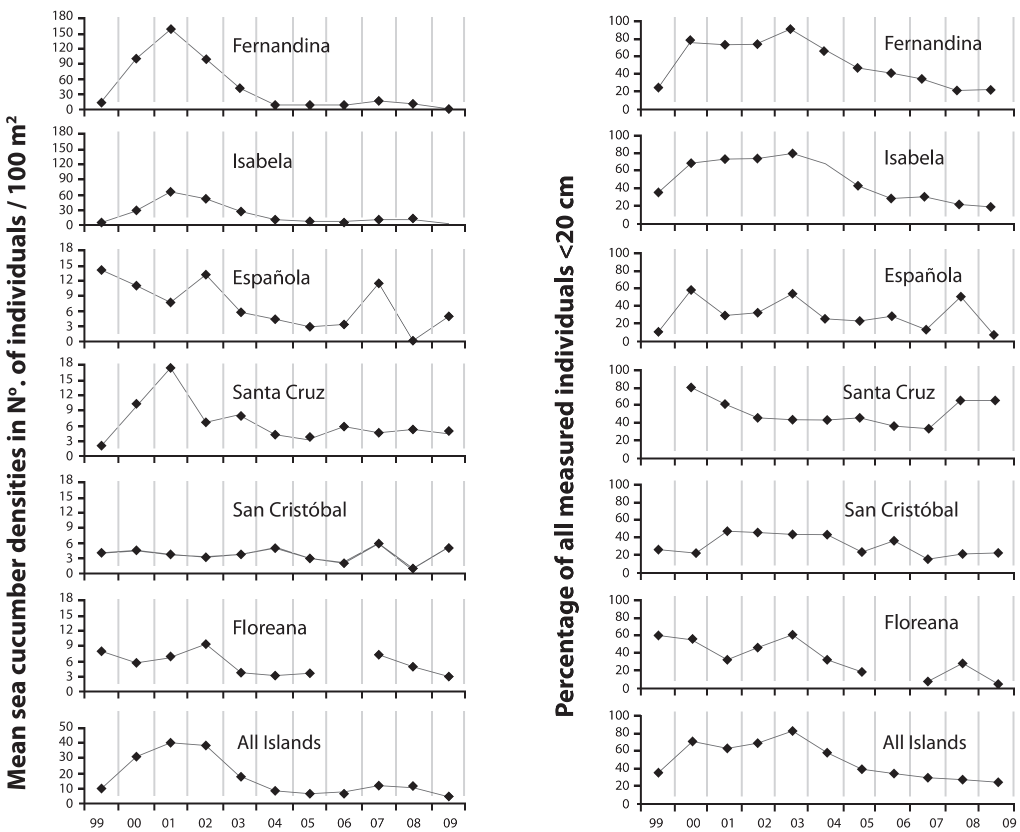



**Figure 4.** Left: pre-fishery monitoring mean densities (ind/100 $m^2$) from 1999-2009, by island. Right: percentage of measured individuals that are smaller than 20 cm in total length, by island (1999-2009).

Mean density values of our 2009 monitoring for the two depth strata were 4.5 and 3.2 ind/100 $m^2$, for 0-15 m and 15-30 m, respectively (Figure 5). The non-parametric Mann-Whitney U test of the median density values confirmed the significant difference found for the mean values using the bootstrapping routine (t-test; $p<0.05$). Accordingly, a higher sea cucumber density in deeper waters, suggested by the fishermen, could not be verified. Instead, higher densities were observed in the shallow stratum.

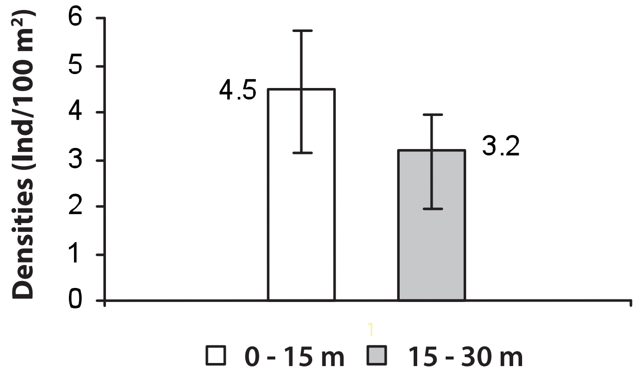



**Figure 5.** Mean densities (ind/100 $m^2$) shown with standard deviation for the two depth strata, after using a re-sampling bootstrap method.

## Discussion

Estimating the fishing area was difficult due to substantial variability in topography and slope of the seafloor between macrozones. Polygon mapping to determine the area ($m^2$) between the coastline and the -30 m isobath using ArcGIS could not always be done without a certain margin of error. However we consider our area estimation a good and necessary starting point to calculate a fishing quota. The fishing season was not opened in 2009, as the sea cucumber density was calculated at a value substantially below the set limit reference point (11 ind/100 $m^2$ in western Isabela). Although the quota calculation of nearly 600,000 sea cucumbers for 2009 was only a virtual quota because the season remained closed, it provides a reference point for the future.

Using the new approach, we calculated a hypothetical quota for each of the past years and then compared them with the annual sea cucumber catches (Figure 6). The newly calculated quotas based on sea cucumber densities from pre-fishery population monitoring were lower than the actual catches during most of the years, except for 1999, 2001, 2007, and 2008, when the quota was slightly higher than the catch.

The rather low sea cucumber catch in 2001 was a result of an individual quota system applied for the first and only time, where each registered fisherman was assigned a quota of 3174 sea cucumbers, which they could use or sell. Many vessel owners bought quotas from other fishermen. However, they miscalculated the economical limit of their fishing activities, which resulted in a total catch of only 60% of the overall quota (2001 CDF-GNP Fishing Report). The virtual quota of 2007 and 2008 is rather high based on the high pre-fishery density estimates, which we believe is based on biased population monitoring and therefore cannot be trusted in the same way as the 2009 estimate.

Of the 459 planned transects, only 383 (83%) were carried out during the 2009 pre-fishery monitoring due to financial constraints. This was the largest

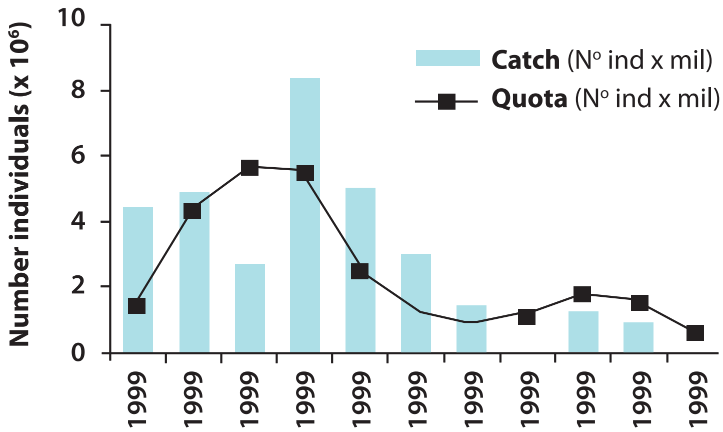



**Figure 6.** Annual sea cucumber catches and the calculated quota based on this study in millions of individuals from 1999-2009 (2006 season was closed).

number of circular transects ever completed in the Galapagos sea cucumber fishing areas during a pre-fishery monitoring. The precision around the mean densities differs between macrozones, with a coefficient of variation (CV) ranging from 12.2% for eastern Española to 81.2% for southern Fernandina (Table 1). These differences can be attributed to the number of transects and the degree of patchiness of the sea cucumbers in each zone. When the transect data are integrated for each island, the respective density estimate is greatly improved, with CVs always <25%. The two islands that had the highest transect numbers (Isabela with 125 and San Cristóbal with 97) had the lowest CV around the mean density estimate (11.6% and 13.3%, respectively). The density estimate for all transects combined (3.93 ± 0.26; CV = 6.8%) can be considered of very high precision.

Of all macrozones sampled, none reached the limit reference point of 11 ind/100 $m^2$ to open the fishery, which points to a very critical state of the stock. Several factors may explain this situation. Since the last strong El Niño in 1997/98, which apparently resulted in improved recruitment of sea cucumbers observed during 2000-2002, the past ten years were dominated by cold waters (Sea Surface Temperature database of CDF) and no further recruitment boom has been observed. This lack of recent recruitment and the problem of a too small spawning stock remaining after each fishing season may have combined to reduce overall spawning activity as well as larval and pre-recruit survival, thus not allowing the sea cucumber stock the chance to recover. Furthermore the catch quotas determined during the co-management process were often too high or not present at all as in 1999 and 2002, leaving behind a stock too small to recover prior to the next season. The general problem was that the quota was set with no available estimate of the absolute stock size.

The belief that sea cucumber densities may be higher in deeper waters, giving the stock a strength in reserve if fishing pressure in shallower waters is high, was shown to be incorrect. This is an important finding since it removes the basis for the argument that a large portion of the stock is out there in deeper waters where it cannot be caught.

We believe that the monitoring and management strategy of the Galapagos sea cucumber stock presented here is an important step towards a sustainable sea cucumber fishery. It is the first time that an attempt has been made to estimate the size of the entire fishing area and of the fishable stock. Moreover, the monitoring was adapted to specific conditions - primarily size and sea cucumber patchiness of each macrozone. The suggested quota was set as a fraction of the stock size (12.2%), which makes it adaptive to natural inter-annual stock fluctuations. If environmental conditions are not too adverse in the coming years, the proposed strategy should allow for sustainable harvests while the sea cucumber stock rebuilds. This strategy also seems economically viable for the management authority since it only considers one annual, pre-fishery monitoring instead of two monitoring surveys as in previous years.

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