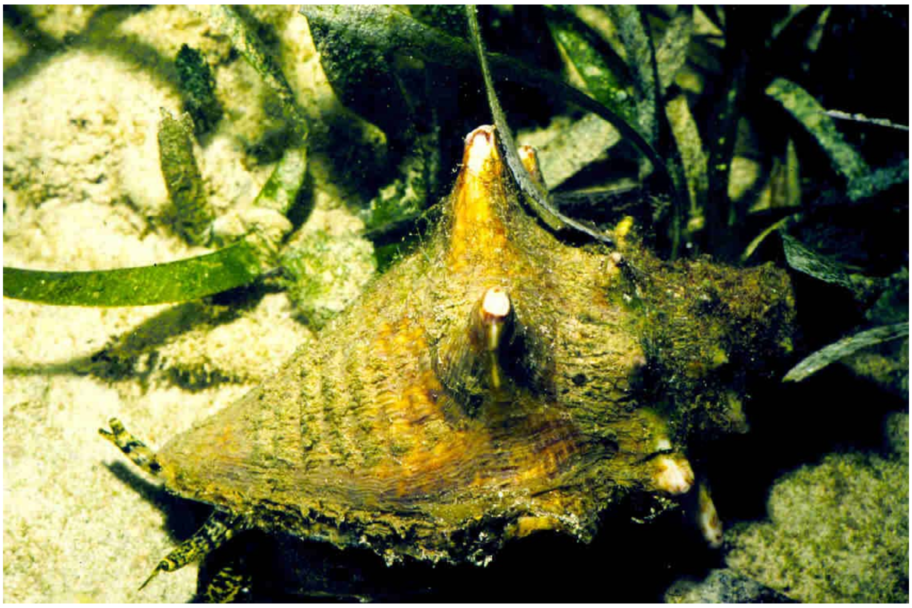
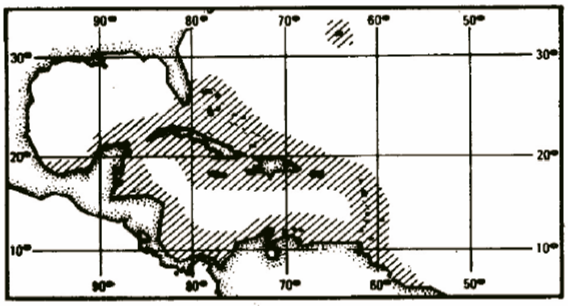
Pressione di pesca e difesa delle popolazioni di *Strombus gigas* nei Caraibi

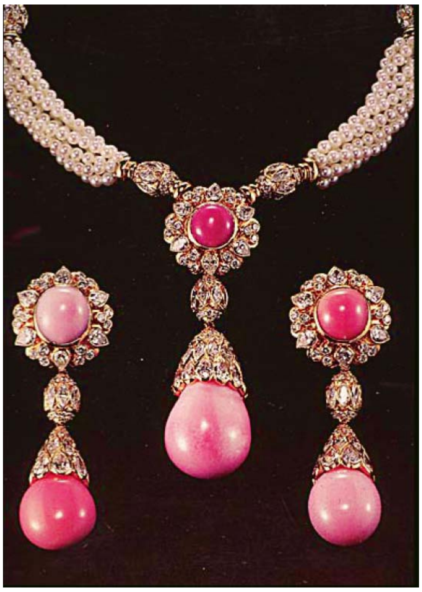
Un esempio di effetto di un'Area Marina Protetta

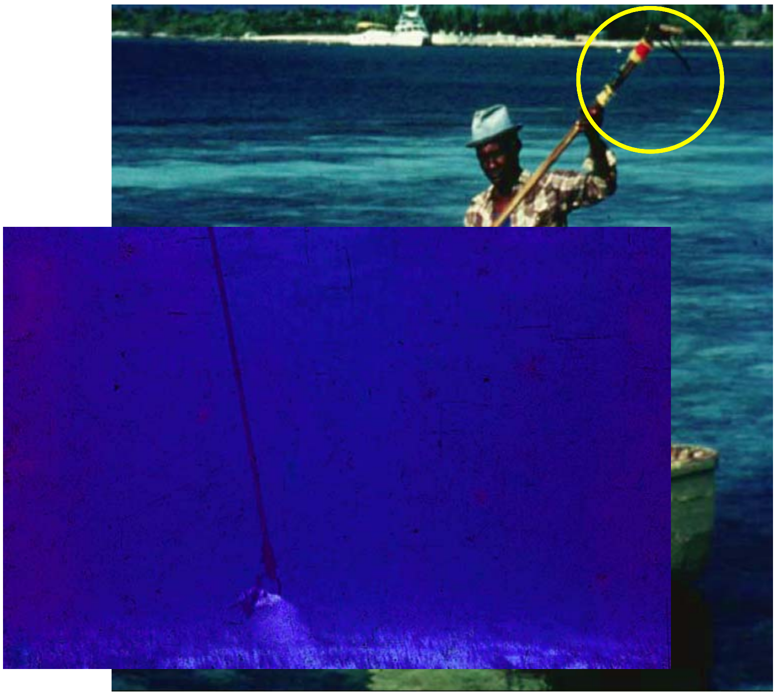
Strombus gigas Linnaeus, 1758



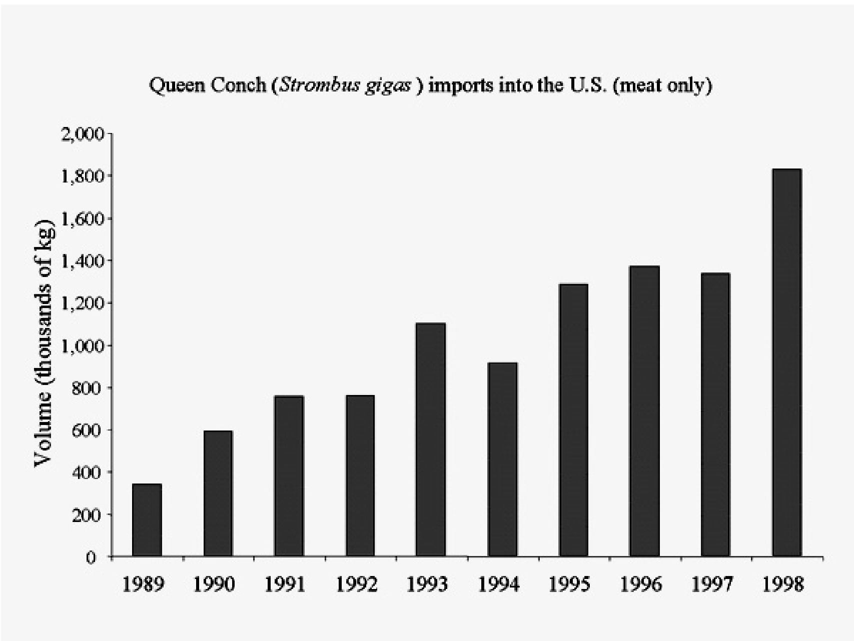


- Comune in praterie di Thalassia e Cymodocea e su fondi sabbiosi fino a 30 m, ma presente fino a 100 m.
- Specie erbivora a sessi separati.
- Le femmine depongono strisce di uova mimetizzate nella sabbia.
- La maturità sessuale è raggiunta a circa 3 anni.
- Taglia massima 32 cm (circa 3 kg), comune intorno a 24 cm.






I cumuli di conchiglie di *Strombus gigas* più antichi (middens, in inglese) risalgono a circa 5000 anni fa.


Queen Conch (*Strombus gigas*) imports into the U.S. (meat only)
Volume (thousands of kg)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

Map courtesy of WorldAtlas.com
CITES report AC19 Doc. 8.3, 2003

- Dal 1992 *Strombus gigas* è stata inserita nella Appendice II dalla Convention on International Trade in Endangered Species (CITES)
- La specie non sembra essere realmente a rischio di estinzione, ma lo sfruttamento incontrollato può compromettere la sua redditività economica
- Altri fattori che minacciano la specie sono legati a cause di degrado ambientale o alla pesca con attrezzi a traino, dannosa per le uova ed i giovani
- Gli stadi giovanili sono abbondanti a bassa profondità, dove è più elevata la possibilità di impatti antropici ed inquinamento

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Biological Evaluation of Marine Protected Area: Evidence of Crowding Effect on a Protected Population of Queen Conch in the Caribbean

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Abstract. This study provides a first evaluation of the biological impact of a marine fishery reserve on the stock of queen conch (*Strombus gigas*) in the Turks and Caicos Islands. The density and the shell length of the population living in the reserve are compared with those of the individuals living in the surrounding fished areas. The results show that the adult density is six times higher in the reserve than in the fished areas. The shell length analysis shows that both adults and juveniles are significantly smaller in the reserve than in the fished area. This unexpected result suggests the existence of a crowding effect (*i.e.* a high density-induced reduction in growth rate) within the reserve. It is hypothesised that this crowding effect is due to the superimposition of two factors leading to very high density values in the reserve: (a) the reduced fishing mortality following the creation of the reserve, (b) the existence of natural barriers that impede the emigration of adults outside the reserve. These results are then discussed in relation to current considerations on marine fisheries reserves.

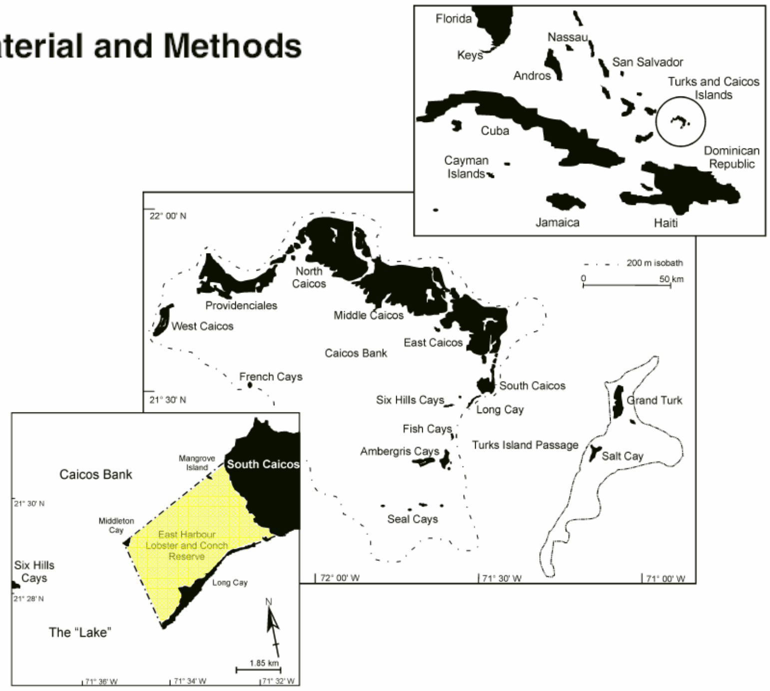
Problem

Marine protected areas (MPAs) have been recently promoted as a viable complement to the other classical forms of fishery management (Robert & Polunin, 1991; Rowley, 1994). One primary objective of MPAs is to ensure a continuous recruitment of commercially targeted species to fished areas via protection of a critical minimum spawning stock biomass. The two mechanisms by which this critical minimum spawning stock biomass is expected to help maintain fishing operations in the adjacent fished areas are: (a) the export of individuals through migration of the target species from the protected to the fished areas (the spillover effect) and (b) the production of eggs resulting from reproductive activity within the reserve and dispersal of larvae over areas outside the reserve (the recruitment effect). In both cases, the underlying concept is that organisms will migrate or diffuse from the protected area to the fished area.

Prior to maintaining, or improving, the yield of the adjacent fished areas, the protection offered by the fishing ban is expected to induce some significant modifications on the population within the reserve itself. Three modifications have been presented in the literature (Roberts & Polunin, 1991). First, if there is no negative density effect on recruitment, the reduced mortality rate within the MPA should increase the abundance of the protected population. Second, the cessation of fishing mortality in the protected areas is also expected to modify the demographic structure of the population, leading in particular to an increase in average size/age reflecting greater longevity of the protected species. Finally, an increase in average size/age may boost egg production, depending on the species size/fecundity relationship.

These three theoretical effects have already been empirically observed through several field studies. Increased egg production of protected populations has been confirmed for spiny lobster (Bertelsen & Hunt, 1999), abalone (Shepherd, 1990), reef fish (Munro, 1983), and estuarine fish (Johnson *et al.*, 1999). Simultaneously, a large number of studies have tested the potential effects of marine reserves on the population structure and abundance of fish (Polunin & Roberts, 1993; Rakitin & Kramer, 1996; Jennings *et al.*, 1996). As expected, most of these studies concluded that fish abundance is higher and the average size is larger within the protected versus the surrounding fished areas (see Roberts & Polunin (1991) or Rowley (1994) for two comprehensive reviews).

Material and Methods



Data was collected from June to November 1998. Belt transects were run at sites chosen randomly (through random choices of Global Positioning System sites) within the fished and protected areas. All data were collected using SCUBA. At each site, 6 × 60 m belt transects were run by two divers, each sampling one side (3 m) of the transect. For each transect, depth (in meters) and substrate/habitat were recorded.

Table 1. Substrate/habitat categories used in characterizing the sites surveyed within the fished and protected areas of the Caicos Bank.

category	code	description
algal plain	AP	fine mud, coarse sand, rubble bottom dominated by benthic algal cover (*Penicillus* spp., *Caulerpa* spp., *Halimeda* spp., *Udotea* spp., *Padina* spp., *Laurencia* spp.)
seagrass meadow	SG	coarse sand bottom dominated by turtle (*Thalassia* spp.) and manatee (*Syringodium* spp.) grass
sand plain	SP	coarse sand bottom with sparse benthic algae or seagrass cover
patch reef	PR	large patches of coral composed of multiple colonies of various morphologies including branching (*Acropora* spp.), boulder (*Montastrea* spp.), and brain (*Diploria* spp.)
coral heads	CH	small patches of coral (dominated by a single colony) of various morphologies scattered within sand bottom
coral rubble	CR	rubble bottom composed of dead and broken coral forming patches with sparse benthic algae or seagrass cover
gorgonian/sponge plain	GS	hard bottom areas with moderate to heavy levels of soft coral (*Plexaura* spp., *Pterogorgia* spp., *Pseudopterogorgia* spp., *Gorgonia* spp.) and sponge cover

The transects were stratified by areas (fished versus protected) and habitats (using the 7 substrate/habitat categories defined in Table 1). All conch found within the transects were counted and their total shell (siphonal) length and shell lip thickness were measured. The conch were then classified into three size/age categories: juveniles, young adults (YA) and old adults (OA) using shell lip thickness and overall shell morphological characteristics (Table 2).

Density analyses. For each site, three densities were calculated: (1) the total density of all conch (*i. e.* with no distinction of size/age category), (2) the juvenile density, and (3) the adult density (sum of YA and OA). A series of statistical tests was then conducted to determine the effect of the "area" factor (fished vs. protected) on population density. First, the potential simultaneous effects of the area and habitat factors were tested on adult density through a two-way analysis of variance (ANOVA). Because a non-normal distribution of the densities was anticipated due to the typical patchiness within conch populations (Berg, 1975; Stoner & Sandt, 1992), density data at each site was log(n+1)-transformed to normalize the distributions.

Secondly, the potential effect of the area factor on conch densities within each habitat was tested through two-sample comparison tests (inter-area, within-habitat comparisons). Due to the failure of the normality condition on the density distributions and the small number of transects ($n < 15$) for certain habitats, distribution-free Wilcoxon-Mann-Whitney (WMW) tests were used for these analyses. The comparisons were conducted on adults and juveniles separately.

Results

Table 3. Details of the sampling survey results for the four habitats: AP = algal plain; SG = seagrass meadow; SP = sand plain; GS = gorgonian/sponge plain. The density values are in conchs · ha^{-1}.

sampling information	number of transects	surface sampled [m^2]		number of conch
fished area	60	30 960[b]		718
protected area	54	19 440		1078
total	114	50 400		1796
habitats	AP	SG	SP	GS
area [a]	f | p	f | p	f | p	f | p
number of transects	24 | 13	8 | 9	20 | 22	8 | 10
adult (OA +YA) mean density	86 | 833	24 | 410	28 | 78	7 | 3
old adult (OA) mean density	50 | 333	17 | 275	11 | 15	7 | 0
young adult (YA) mean density	36 | 500	7 | 135	17 | 63	0 | 3
juvenile conch mean density	331 | 483	497 | 179	85 | 232	24 | 21

Note: [a] Area: f = fished; p = protected. [b] 6 × 120 m belt transects were used (instead of the 6 × 60 m standard ones) for the 26 most remote transects (South West limit of the Caicos Bank) in order to minimize SCUBA equipment pre- and post-dive handling and thus maximise the area sampled for these rare sampling opportunities.

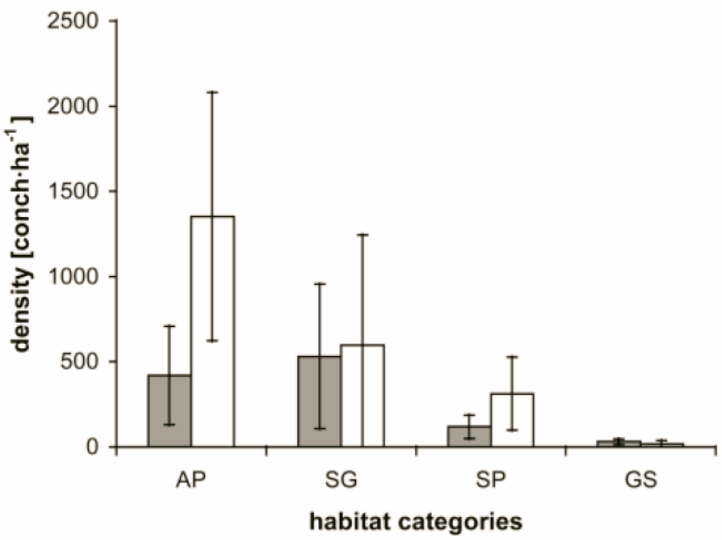


Fig. 2. Mean densities (± 95 % confidence interval) of queen conch for different habitats in fished and protected areas of the Caicos Bank (fished = shaded bars, protected = clear bars). AP = algal plain; SG = seagrass meadow; SP = sand plain; GS = gorgonian/sponge plain.

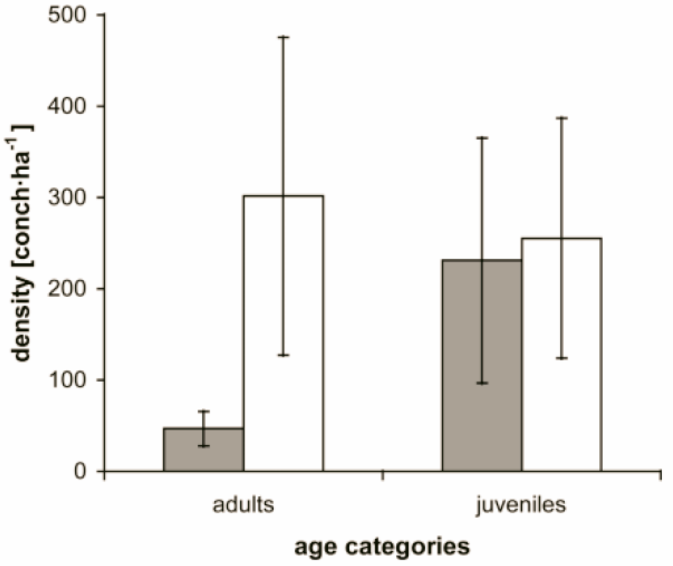


Fig. 3. Mean densities (± 95 % confidence interval) of adult and juvenile queen conch in fished and protected areas of the Caicos Bank (fished = shaded bars, protected = clear bars).

Table 4. Test of the effect of the two factors (area and habitat) on adult conch density through a two-way mixed ANOVA. $F_{0.05(1,52)} = 4.03$; $F_{0.05(3,52)} = 2.79$.

source of variation	df	SS	MS	F	P-value
random factor (habitat)	3	33.37	11.12	14.68	< 0.001
fixed factor (area)	1	4.41	4.41	5.82	< 0.025
interaction (area × habitat)	3	3.71	1.24	1.63	0.087
within subgroup (error)	52	39.41	0.76		
total	59				

Table 5. Inter-area, within-habitat comparisons of the adult and juvenile densities through Wilcoxon-Mann-Whitney tests [a]. AP = algal plain, SP = sand plain, and SG = seagrass meadow, n = number of transects, f = fished, p = protected.

population	habitat	n (f | p)	mean rank (f | p)	sum of ranks (f | p)	P-value
adult	AP	24 | 13	13.90 | 28.42	333.5 | 369.5	< 0.001
	SP	20 | 22	17.20 | 25.41	344.0 | 559.0	0.024
	SG	8 | 9	6.69 | 11.06	53.5 | 99.5	0.074
juvenile	AP	24 | 13	17.67 | 21.46	424.0 | 79.0	0.321
	SP	20 | 22	19.13 | 23.66	382.5 | 520.5	0.226
	SG	8 | 9	10.75 | 7.44	86.0 | 67.0	0.200

Note: [a] The tests were conducted under a one-tailed approach since, from Fig. 2, the densities in the protected areas were higher than in the fished areas.

The Battacharya technique permits the identification of three cohorts (modes) within the juvenile population and allows estimation of their mean siphonal lengths.

Table 6. Inter-area comparisons of mean siphonal lengths [mm] for young and old adults (YA and OA) and the three juvenile cohorts (noted 1, 2, 3) through least significant difference (LSD) tests. Critical value z_α = 1.644 (α = 0.05), n = number of observations, f = fished, p = protected.

category/cohort	mean length (f | p)	SE (f | p)	n (f | p)	z	P-value
1	104 | 97	12 | 9	237 | 202	6.99	< 0.001
2	152 | 138	13 | 15	168 | 97	81.14	< 0.001
3	196 | 187	13 | 10	115 | 140	79.57	< 0.001
YA	214 | 193	20 | 18	79 | 378	8.468	< 0.001
OA	204 | 186	23 | 19	115 | 253	7.234	< 0.001

Table 8. Inter-area, within-habitat comparisons of mean siphonal lengths [mm] of the juveniles, young adults (YA) and old adults (OA) through heteroscedastic t-tests (two-sample unequal variance t-test, α = 0.05), f = fished, p = protected, AP = algal plain, SG = seagrass meadow, and SP = sand plain.

size/age cat.	habitat	mean length (f | p)	SE (f | p)	t_{obs}	t_α	P-value
juveniles	AP	158 | 135	39 | 38	6.87	1.03	< 0.001 ←
	SG	150 | 151	34 | 30	0.058	1.66	0.476
	SP	141 | 108	46 | 26	5.60	1.66	< 0.001 ←
YA	AP	218 | 192	20 | 17	8.26	1.67	< 0.001 ←
	SG	199 | 187	7 | 15	2.27	2.13	0.042 ←
	SP	211 | 204	18 | 10	1.92	1.67	0.030 ←
OA	AP	205 | 187	22 | 19	6.88	1.65	< 0.001 ←
	SG	197 | 179	19 | 12	2.06	2.13	0.053
	SP	203 | 204	18 | 21	−0.04	1.78	0.484

Taglia media nelle aree di pesca > taglia media nell'AMP

Discussion

1. Expected effects of the MPA on conch density

The analysis shows that both global and within-habitat adult mean densities are generally higher in the protected area than in the fished areas. This trend is confirmed statistically for AP and SP habitats, while the difference is slightly below the significant threshold for SG ($P = 0.074$). These results suggest that the protective management induces higher adult densities in the protected area, regardless of habitat. In contrast, for juveniles, the differences between the densities for the three different habitats within and outside the protected area are not significant. This conforms to expectations since fishing (other than poaching) should have no effect on juvenile mortality.

2. Unexpected effects of the MPA on conch growth

The comparisons of lengths between protected and fished areas show that the mean siphonal lengths of the three juvenile cohorts and of both adult categories (YA and OA) tend to be smaller within than outside the EHLCR (Table 6). These unexpected results suggest that conch have lower growth rates in the protected area.

This difference in growth rate may be explained by different ecological factors. Three factors have been reported in the literature to influence conch growth rate: depth, habitat types, and intra-specific competition.

Effetto profondità

In the present study, however, all the samplings were done in very shallow waters (average of 5.2 ± 2.4 m for fished and 3.2 ± 1.9 m for protected areas) and the difference in the mean depth is only 2 m. With such a narrow depth range, and since the protected area is on average shallower than the fished area, it is reasonable to assume that depth is not the source of difference in the juveniles' growth rate.

Effetto habitat

In the present study, analyses were therefore performed after habitat stratification in order to separate the potential effect of the habitat from that of the area. Not surprisingly, our analysis (within-area, inter-habitat comparisons of mean lengths) indicates that habitat type has an effect on conch size in agreement with the aforementioned studies. But the novel aspect of this study is the result of the inter-area, within-habitat, mean length comparisons. These comparisons clearly show that individuals are growing slower in the protected than in the fished areas, regardless of habitat effects.

Competizione intraspecifica

Considering the greater overall densities in the protected area, it is possible that these differences in growth rates are due to intra-specific food competition resulting from very high densities. Several studies have already demonstrated such an effect in culture (Appeldoorn & Sanders, 1984), laboratory experiences (Siddall, 1984) or artificial enclosure experiences (Stoner, 1989). All these studies conclude that growth rate is highly density-dependent and in particular that conch grow more slowly at higher densities.

In the present case, the mean densities in the reserve (254 for juveniles and 301 conchs · ha^{-1} for adults) are amongst the highest observed in the natural environment.

Conclusions

Although the initial purpose of the study was to provide a first evaluation of the biological impact of an MPA on the local stock of queen conch – the data suggest that the creation of the MPA increased conch density within the protected area – the study also highlights the unexpected occurrence of a crowding effect, which affects the growth rate of the protected population. Several studies (Siddall, 1984; Appeldoorn & Sanders, 1984; Stoner, 1989) had already shown the effects of density on conch growth in artificial enclosures or culture systems. The present study is the first to suggest that high densities can also reduce the growth rate of *Strombus gigas* in its natural environment. This density-dependent phenomenon is difficult to assess. It probably occurs naturally in the environment, but in the EHLCR has become much more observable due to the superimposition of two factors: (a) the reduced fishing mortality following the creation of the EHLCR and (b) the natural barriers that enclose the protected conch within the newly established reserve (Tewfik & Béné, in press). This combination leads to very high densities within the park, which, in turn, induces a strong intra-specific competition in all the habitats and leads to a general crowding effect throughout the protected area.

Cosa abbiamo imparato?

- Rimuovere la pressione di pesca è un'opzione, non una necessità assoluta.
- Le interazioni biotiche devono essere sempre considerate (e non è sempre così facile – alcune non le immaginiamo neppure).
- La scala spaziale è sempre un fattore importante (si sarebbe avuto lo stesso risultato con più aree di piccola dimensione?
- Non diamo per scontato nessun risultato.

Domande aperte

- Se invece che di un erbivoro si fosse trattato di un predatore, il risultato sarebbe stato diverso?
- Se lo studio fosse stato replicato nel tempo, cosa avremmo potuto sapere di più?
- Che effetti possono determinarsi nel caso di organismi più mobili di *Strombus gigas*?
- Le nostre AMP possono incorrere in questo tipo di problemi?