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Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands

TERMINATION REPORT

ACIAR Project No. FIS/1994/117
ICLARM Contribution No. 1609

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Marcus P. Lincoln Smith,
Johann D. Bell,
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and Kylie A. Pitt

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December 2000

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EXECUTIVE SUMMARY

Termination Report for ACIAR Project No. FIS/1994/117

Project Title

Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands

Commissioned Organisation

The commissioned organisation was The Great Barrier Reef Marine Park Authority, who contracted The International Centre for Living Aquatic Resource Management (ICLARM) and The Ecology Lab Pty Ltd to implement field studies and prepare reports.

Collaborating Institutions

- The Nature Conversancy (TNC).
- The Solomon Islands Division of Fisheries.

Project Leaders

- Australia ñ Dr Marcus Lincoln Smith, Director, The Ecology Lab Pty Ltd.
- Solomon Islands ñ Dr Johann Bell, ICLARM; George Myers, TNC and Peter Ramohia and Michelle Lam, Division of Fisheries.

Date of Commencement

October, 1994

Date of Completion

February, 2000

Aim of the Project

To determine if the number and size of commercially important invertebrates (e.g. trochus, sea cucumbers and giant clams) increases as the result of the declaration of the Arnavon Islands Marine Conservation Area (MCA) relative to fished areas.

Description of the Work

A pilot study was done in October 1994 to assist in selecting sampling sites and refining sampling methodology. Three surveys were then done at the Arnavon Islands, and at three reference areas, from January to August 1995, before the MCA was declared. Interim surveys after declaration were done in September 1996 and 1997. Three final surveys, were done in September 1998, January 1999 and April 1999. In all eight surveys, invertebrates were sampled in two habitats, shallow reef terrace (depths 0.5 to 3.5 m) and deep slope (15 to 22 m). For each habitat, four sites were surveyed at each of two islands within each of four areas, i.e. the MCA and three reference areas (Suavanao, Ysabel and Waghena).

In the shallow habitat, six transects (each 50 m long) were laid across the reef terrace and invertebrates were counted within 1 m either side of each transect, giving an area per transect of 100 m^2. Invertebrates of interest included trochus, sea cucumbers, giant clams and pearl oysters. In the deep habitat, six 50 m long transects were laid roughly parallel to the depth contours and invertebrates were counted over a 5 m wide strip (total area per transect = 250 m^2). The invertebrates of interest in the deep habitat were sea cucumbers.

All invertebrates of commercial importance observed within transects were counted and measured. In addition, some invertebrates seen outside transects were measured to increase the data available for analysis of length-frequency distributions.

The data obtained for the three surveys done prior to declaration of the MCA, and those obtained for the last three surveys, were used to test the effectiveness of the MCA. Data for the two habitats were analysed separately.

Asymmetrical analysis of variance (ANOVA) was used to compare abundances of invertebrates within the Arnavon Islands to the three reference areas before and after declaration of the MCA. This approach provided an indication of the spatial (i.e. area or group, island, site and transect) and temporal (i.e. before vs after and individual surveys) scales at which the greatest changes occurred. This type of experimental design is frequently used to monitor the impacts of human activities on the marine environment and its use here represents a significant innovation in studying the effectiveness of marine reserves. Unfortunately, this approach was generally not available for analysis of length-frequencies, due to a paucity of data. For the length frequency data, modified designs were used, or data were interpreted graphically.

Results, Conclusions & Assessments

1 Four categories of results were observed for abundances of invertebrates. Numbers increased at the Arnavons from before to after the declaration of the MCA and numbers remained similar, or declined at the reference locations. This was observed for *Trochus niloticus* in the shallow habitat and for white teatfish in the deep habitat. These results indicated that the establishment of the MCA had led to an increase in the number of commercially important invertebrates of these species.

2 Numbers remained similar at the Arnavons from before to after the declaration of the MCA, but numbers declined at the reference locations. This was observed for total holothurians in the deep habitat and, although the evidence was not conclusive, for amberfish in the deep habitat. This indicated lack of recruitment during the study and the ongoing effects of harvesting of these species at the reference areas (i.e. where fishing was not prohibited).

3 Similar changes in abundance occurred at both the MCA and reference locations from before to after the declaration of the MCA. This was observed for all giant clams combined, *Tridacna maxima* and greenfish in the shallow habitat and for elephant trunkfish in the deep habitat. This indicated no effect of the MCA for these species.

4 Numbers remained similar at the Arnavon Islands and increased at the reference locations from before to after the declaration of the MCA. This was observed for *Tectus pyramis*, the only non-commercial species examined. This finding is difficult to interpret, but the trend may be due to less competition for space between *Tectus* and *Trochus* at reference areas, due to the small numbers of the latter.

Results of size analyses were varied. The mean size of *Trochus niloticus* increased after the declaration of the MCA, however the mean size of white teatfish decreased, due to recruitment of small individuals into the population. The MCA appeared to have no effect on sizes of other species.

Overall, the declaration of the MCA has led to success in restoring abundances and sizes of some invertebrates at the Arnavon Islands. The findings of the study, however, demonstrate that more time is necessary to identify the period needed for recovery of several species and strongly support the continuation of the MCA and the monitoring program.

Publications

One paper has been published from the study are three are in preparation. Several progress reports during the study, together with a manual outlining sampling locations and methods were also prepared. The title of the paper is:

Lincoln Smith, M. P., Bell, J. D., and Mapstone, B. D. (1997). Testing the Use of a Marine Protected Area to Restore and Manage Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Choice of Methods and Preliminary Results. In: *Proceedings of the 8th International Coral Reefs Symposium, Panama,* 1996, Volume 2: 1937 - 1942.

Of the three papers being written, one is being prepared for submission to *NAGA* on the topic of management issues associated with the study. The others are scientific papers on the full results of the study.

Follow-up

There are three main areas that should be considered for follow-up; two of these are related to the studies at the Arnavon Islands, the third is related to expansion into other areas.

The first is to continue the present study at the MCA and reference areas, preferably for a further three years (with surveys in September September 2001, September 2002, January 2003 and April 2003). This would enable us to measure possible further increases in the abundance of trochus in the MCA and, hopefully, to identify when a stronger effect would be detected for sea cucumbers.

Continuing the study under this framework would result in an almost continuous annual set of data from 1996 to 2003. It would also provide a third temporal component to the asymmetrical ANOVA (using the September 2002 and January and April 2003 surveys), by enabling a comparison of pre-MCA with three years post-MCA and six years post-MCA. This would provide a powerful basis for assessing the effectiveness of the MCA.

The second area of follow-up is to commit some extra resources to sampling additional sites within the MCA. This is because great variation in recovery rates were observed among sites and it would be beneficial to examine whether the variability examined among sites encompassed the range of natural variability observed within the MCA. This would be outside the framework of the asymmetrical approach, but, given the importance of individual sites in recolonisation of the MCA, it could provide a much clearer pattern of changes in abundance and richness through the MCA. Previously, eight sites were sampled in each habitat within the MCA. It is recommended that sampling be done in a further eight sites within the MCA in September of 2001, 2002 and 2003 (i.e. 16 sites in total).

These two areas of follow-up both need the support of the local communities and would require that harvesting of marine invertebrates in the MCA continue to be prohibited. It also requires continued use of Conservation Officers to patrol and monitor activities within the MCA. In order to facilitate this, the TNC and Solomon Islands Government would need to maintain their support for the project.

The third area of follow-up involves expanding the study to other areas within the region, country and possibly to other Pacific Island nations. During the study, some of the local communities expressed interest in setting aside other coral reefs as marine reserves. The Arnavons MCA could form the nucleus and/or model for a series of marine reserves within the region, which, in turn, could be a valuable experience applicable to other nations in the tropical Pacific. The best approach for achieving this will be to ensure that appropriate scientific and managerial rigour are applied to any further reserves and that the findings of the present study are properly disseminated.

1.0 BACKGROUND

As humans first exploit and then potentially over-exploit living resources, there is often a recognition that areas need to be set aside to help protect or restore these resources. This concept has been applied in both terrestrial and aquatic ecosystems and has, in many cases, led to the declaration of aquatic reserves or parks. Within the marine environment, there has been a broad expansion of the use of marine reserves over the last four decades.

Good summaries of the potential benefits of marine reserves to the management of fisheries are provided by Bohnsack (1993), Carr and Reed (1993), Dugan and Davies (1993), Polunin and Roberts (1993), Sladek Nowlis and Roberts (1997, 1999), Babcock *et al.* (1999), Parrish (1999) and Kelly *et al.* (2000). Briefly, these include:

1) Conservation of habitats, species diversity and genetic diversity (so-called heritage benefits - Parrish 1999).
2) Maintenance of large populations of organisms and large individuals within such populations, leading to increased egg production.
3) Sources of propagules to replenish areas depleted by over-exploitation.
4) Replenishment of adjacent, non-protected areas by movement of larger individuals (e.g. either by random movement or density dependent processes).
5) Changes in habitat structure due to changes in habitat-forming organisms (e.g. increases in benthic primary productivity as an indirect result of changes in fishing activity - Babcock *et al.* 1999).

Whilst there are strong theoretical arguments in support of these benefits, the evidence from field investigations is less compelling. Based on the scientific literature, it would be difficult to demonstrate unequivocally the replenishment of non-protected areas, either through supply of propagules or movement of larger individuals. Carr and Reed (1993) argued that the extent to which reserves may supply propagules to non-protected areas depends on numerous factors, including locations of reserves and non-protected areas relative to larval duration, local currents and the size of reserves. Demonstrating a significant reserve effect in terms of larval supply may require examination of samples at the genetic level to trace biota between sites (Carr and Reed 1993).

To demonstrate unambiguously the effects of a marine reserve, it is necessary to monitor populations within the reserve and at reference locations prior to, and for some time after, declaration. This type of approach is analogous to sampling often done for environmental impact assessment, where changes in mean diversity and abundance at an impact site are compared against appropriate spatial and temporal controls. Carr and Reed (1993) suggested that, for the purpose of such analysis, the reserve can be considered an "impact" on species of interest.

In the mid-1990ís, an opportunity to test some of the theory on marine reserves arose in Solomon Islands. The Nature Conservancy (TNC) negotiated with local fishermen a total closure on fishing of commercially important invertebrates (mainly trochus, sea cucumbers and giant clams) for three years within The Arnavon Islands Marine Conservation Area (MCA). The Arnavon Islands consist of two main islands, Kerehikapa and Sikopo, which lie in the Manning Strait, between Choiseul Island and Ysabel Island, in Solomon Islands (Fig. 1). The MCA covers an area of approximately 83 km^2 and was traditionally an important area for harvesting turtles, marine invertebrates and fish. The closure came into effect in September 1995 and has continued to this time.

The International Centre for Living Aquatic Resources Management (ICLARM) informed the Great Barrier Reef Marine Park Authority (GBRMPA) of the opportunity to study the effects of fishing protection on commercially exploited invertebrates at the Arnavon Islands. GBRMPA obtained an ACIAR Small Grant to work with ICLARM and TNC to study the effects of the fishing closure.

This is one of the few studies of the effects of marine protected areas that involves sampling a conservation area and a suite of reference areas that remain open to fishing, before and after the implementation of the fishing closure (cf. Kelly *et al.* 2000). It is also unusual in that it focuses on the effects of fishing on tropical marine invertebrates, rather than fish.

2.0 OBJECTIVES

The overall aim of the study was:

To determine if the number and size of commercially important invertebrates (e.g. trochus, sea cucumbers and giant clams) increases as the result of the declaration of the Arnavon Islands Marine Conservation Area (MCA) relative to fished areas.

As discussed more fully in Section 3.1, marine reserves are seen as a means of conserving biodiversity and stocks of commercially important fish and invertebrates in the oceans. They may also help to enhance stocks outside reserves, for example by sheltering reproductive populations from depletion, which may then help to "seed" other areas. The use of marine reserves in tropical ecosystems may be particularly important as many species occur together on coral reefs and they can be reduced dramatically, and simultaneously, by overfishing, much of which is based on multispecies fisheries.

Marine reserves may also influence the sizes of individuals and, therefore, reproductive output. Commercial harvesting of species frequently causes a decrease in the mean size of individuals, since large animals are usually targeted. Release of fishing pressure via the creation of a marine reserve could affect sizes in two ways. Sizes may increase due to the release of fishing pressure on larger size classes, or sizes may decrease if there is substantial recruitment of juvenile animals into the population.

Unfortunately, many of the scientific investigations of the effectiveness of marine reserves have been sub-optimal in one or two ways. First, they often do not have data from the marine reserve prior to its declaration and, second, they often lack comparisons with non-protected areas. Both these sources of information are essential for providing an unambiguous test of the effectiveness of a marine reserve. The declaration of the MCA, in conjunction with the design of an effective monitoring program, provided the opportunity to rigorously test of some of the claims made for marine reserves. Such information is needed to empower local communities to make informed decisions about the value of fishing closures, and for the general management of marine reserves.

In achieving the aim of the study, several specific objectives had to be met. These were:

- A pilot investigation initiated to select sampling sites and develop appropriate sampling procedures.
- Estimation of the abundance and size of commercially important invertebrates at the Arnavon Islands, and at several reference areas, on three occasions prior to the declaration of the MCA.
- Annual surveys of the abundance and size of commercially important invertebrates, within the MCA and reference areas, including liaison with local communities.
- Estimation of the abundance and size of commercially important invertebrates on three occasions, three years after declaration of the MCA, to provide a formal test of the effectiveness of the MCA.
- Use of current best practice in experimental design and statistical analysis to provide a rigorous and objective test of the effectiveness of the MCA.

All of these objectives were achieved successfully. It should be noted that the objective to conduct annual surveys was not part of the original project description. These surveys were added to the study following the pilot investigation as a means of obtaining interim data on the MCA. They were also very important in maintaining the interest of national scientists and conservation officers, and local communities, in the project.

3.0 DESCRIPTION OF THE PROJECT

3.1 Previous Relevant Studies

A major problem in evaluating the effects of existing marine reserves on harvested populations and communities has been the lack of data collected prior to establishment of the refuge (Dugan and Davies 1993). There are numerous examples of this problem from both temperate and tropical regions, including the Philippines (Russ and Alcala 1989), Australia's Great Barrier Reef (Ferreira and Russ 1995), Africa (McClanahan 1995, Watson and Ormond 1994), the Caribbean (Roberts and Polunin 1993, Roberts 1995), California (Carr and Reed 1993) and New Zealand (Cole *et al.* 1990). Many scientists have argued that marine reserves have substantial benefits for conservation of aquatic communities and maintenance of harvestable stocks (Ballantine 1991, Ivanovici *et al.* 1993 and papers therein, Roberts and Polunin 1991, 1993, Russ 1991, Bohnsack 1993, Carr and Reed 1993, Dugan and Davies 1993). Others have pointed-out, however, that setting aside areas for marine reserves can have great social and economic cost for those who previously derived food, employment or recreational benefit from those areas (Bergin 1993). Therefore, scientists and managers need to assess whether specific reserves deliver the benefits attributed to them, and then inform those whose livelihoods are affected by the closure.

De Martini (1993) examined potential replenishment of non-protected areas adjacent to marine reserves by computer modelling based on growth curves and mobility of Pacific coral reef fishes. He asserted that there was little empirical evidence to suggest that reserves replenished non-protected areas, citing Russ and Alcala (1989) as the best (but still inconclusive) evidence from the field.

Most of the work done on marine reserves has focused on the first two benefits listed above, namely, species diversity/abundance and size (or, more recently, age structure - see Ferreira and Russ 1995). The design of field studies for this work usually includes sampling the reserve and one or more non-protected areas (as control or reference sites) but excludes, in most cases, sampling of reserve and non-protected areas prior to declaration of the reserve. Thus, in most cases, there is no measure of the extent to which reserve and non-protected areas differ due to natural variability, or to an effect due to the reserve.

In order to cast doubt on many of the earlier studies, one merely needs to demonstrate that: 1) variability among sites in the absence of a marine reserve is of a similar magnitude to that reported between reserve and non-protected sites; or 2) that variability through time within a site not subject to protection is comparable to variability within a site before and after it is declared a marine reserve.

Dugan and Davies (1993) summarised studies comparing reserve and non-protected areas and found that reserves had two to 13 times more individuals than non-protected areas. However, this trend may be explained by the original selection of the reserves, which may have had intrinsic natural features that supported naturally large populations of marine organisms.

3.2 The Situation in the Pacific

The tropical Pacific encompasses a vast area and many independent states. Many of the people living in the region rely almost totally on marine resources for food, recreation, culture and cash income. Management of fisheries stocks on coral reefs is difficult using traditional methods and marine reserves potentially offer an effective management tool (Roberts and Polunin 1993). The World Conservation Union (IUCN) and the South Pacific Regional Environment Program (SPREP) have initiated a cooperative program to promote the establishment of a system of marine protected areas (MPAs) within the tropical Pacific. Despite the large size of the region, only 67 MPAs had been established by 1994 (Kenchington and Bleakley 1994) and, until the present project commenced, none had been declared in Solomon Islands, other than two small closures to fishing in the vicinity of the ICLARM research facilities.

Programs seeking to encourage declaration of marine reserves within the tropical Pacific will be able to promote this management tool far more easily if the benefits of reserves are evaluated and documented. In the present study, the planning and management of the MCA at the Arnavon Islands was implemented in conjunction with a program to monitor the success of the MCA in facilitating an increase in the populations and sizes of harvested invertebrates. This has been done using a rigorous, quantitative survey program based on the procedures developed for environmental impact assessment (Underwood 1989, 1993).

Large invertebrates are an important part of the local fisheries in Solomon Islands - such species are relatively easy to harvest, can be preserved without refrigeration, and yield significant export income (Richards *et al.* 1994). Important groups of invertebrates include giant clams, pearl oysters, trochus and holothurians (known commonly as sea cucumbers and processed into beche-de-mer). There is information - mostly in terms of export volumes - to suggest that these invertebrates are either fully or over-exploited (Richards *et al.* 1994 and references therein). There is some regulation of harvesting at the government level (e.g. maximal and minimal size limits on trochus and bans on the export of wild giant clams and pearl oysters). There are also regulations on harvesting at the community level. For example, in Ontong Java, harvesting of white teatfish (*Holothuria fuscogilva*) sea cucumbers is prohibited during alternate years (Holland 1994). The limited information available suggests, however, that such measures are not enough to sustain the present rates of harvest. One management measure that has been suggested is the establishment of sanctuaries to provide stock, whose propagules can replenish surrounding areas on a regular basis (Richards *et al.* 1994).

3.3 Study Participants and Linkages

The major participants in the study included:

- The Nature Conservancy (TNC), which negotiated the original MCA, took responsibility for training and support of the Conservation Officers (COs) and provided some of the equipment for the study.
- ICLARM, which recognised the need for the project, designed the sampling program and provided logistical support and equipment for the study.
- ACIAR as funding agency.
- The Government of Solomon Islands, which assisted in the management and support of the COs, provided Fisheries Officers to assist with sampling and made the Daula and its crew available as a support vessel for the project.
- GBRMPA, which provided scientific and management support, including peer review of the study.
- Dr Marcus Lincoln Smith of The Ecology Lab Pty Limited, who was engaged by GBRMPA as Project Scientist.

There was strong collaboration between all participants to ensure that the project was planned and executed successfully. Linkages also extended to the publication of study findings and the training of Solomon Islanders in practical and theoretical aspects of the study (see below).

3.4 Timetable

The timetable for the project reflected the objectives listed in Section 2. The Pilot Investigation was completed in October 1994, followed by the three surveys prior to declaration, which were done in January-February, April-May and July-August 1995. The annual interim surveys were done in September ñ October 1996 and 1997. The final three (post-declaration) surveys were done in September 1998, January-February 1999 and April 1999.

4.0 PROJECT ACTIVITIES - FINAL YEAR

Results for the previous years of the project are reported in Lincoln Smith (1994, 1996), Lincoln Smith and Bell (1996) and Lincoln Smith *et al.* (1997). This report completes the documentation for the project.

4.1 Progress of Research Work for the Final Year

4.1.1 Sampling Locations and Times

Sampling was done in two reef habitats, shallow reef terraces (depth range 0.5 to 3.5 m) and deep slopes (15 to 22 m). The reef terrace habitat consisted of flat reef pavement with live and dead coral and patches of sand. The substratum of the deep slope habitat was generally made up of sand and/or coral rubble. These habitats were described semi-quantitatively in Lincoln Smith and Bell (1996), where it was concluded that any habitat differences among sites would be unlikely to cause any bias in the surveys of invertebrates.

For each habitat, four sites were surveyed in each of two islands within each of four areas i.e., the Arnavon Islands MCA (Plate 1) and three reference areas or groups ñ Suavanao, Ysabel and Waghena (Fig. 1). Commercial harvesting of invertebrates occurred at all reference areas. The number of sites sampled for each habitat was 32, giving a total of 64 sites sampled during every survey. A brief description of each site and its latitude and longitude are presented in Table 1.

Eight surveys have been undertaken at all of the sampling sites. These include January-February, April-May and July-August, 1995; September-October, 1996, 1997 and 1998; and January-February 1999 and April 1999.

4.1.2 Methodology

4.1.2.1 SHALLOW TERRACE HABITAT

The invertebrates counted in this habitat were giant clams, trochus (*Trochus niloticus*), sea cucumbers, pearl oysters and false trochus (*Pyramis tectus*). The false trochus is not commercially valuable and was included to provide a comparison with harvested species. False trochuses were counted but not measured. Sea cucumbers commonly encountered in this habitat included lollyfish (*Holothuria atra*), orangefish (*Bohadschia graeffei*), greenfish (*Stichopus chloronotus*), surf redfish (*Actinopyga mauritiana*) and stonefish (*Actinopyga miliaris*).

The survey procedure for the shallow habitat was as follows. One SCUBA diver descended to the terrace, anchored a tape and swam in a straight line over the terrace to the 50 m mark on the tape. If there was a noticeable current, the diver laid the transect swimming into the current, so that it was easier for the observer to do the survey. The line was laid haphazardly with respect to depth, rather than along a depth contour.

A second diver (the observer) swam along the tape holding a PVC "t-bar", which was a 2†m long pipe with a handle and was used to define the transect width of 2 m (Plates 2, 3 & 4). Transects of four different sizes were compared during a pilot study conducted in 1994 (Lincoln Smith 1994, Lincoln Smith *et al.* 1997). 50 x 2 m transects were selected for sampling the shallow habitat since they provided adequate precision and several replicate transects could be completed during one SCUBA dive. The observer counted invertebrates within each transect and recorded the depth and time at the start and finish of each transect. Once the transect was surveyed, the first diver retrieved the tape and, after swimming for 10-20 m, re-laid the tape in a different direction. If the water depth was < 1.5 m, observers did the shallow survey using snorkel rather than SCUBA. If the depth was > 1.5 m, the observer always used scuba to maintain the efficiency of the survey.

Two teams of divers sampled invertebrates along three transects at each site, giving a total of six transects for each site.

All the exploitable invertebrates counted within transects were measured to the nearest 5†mm in length, except trochus, which were measured to the nearest 1 mm. When time permitted, invertebrates seen outside the transects were also measured (but not counted) to increase the sample size for estimating size-frequency distributions. Measurements were done as follows. Sea cucumbers were measured from the mouth to the anus of the animal, over the top of the body, using a fibreglass tape measure. Each sea cucumber was disturbed as little as possible and the measurements taken quickly, so that there was minimal chance of the sea cucumber changing shape. Clams were measured along the top of the shell, as it was not possible to measure shell width because many individuals were buried. Trochus (*Trochus niloticus*) were measured across the widest point of the shell base. Pearl oysters were measured from the apex to the hinge of the shell.

4.1.2.2 DEEP SLOPE HABITAT

Surveys in the deep habitat were done along coral, rubble and sand slopes. Sea cucumbers and goldlip and blacklip pearl oysters occurring in the deep habitat were counted and measured. The deep habitat contained some of the most valuable species of sea cucumbers, including white teatfish (*Holothuria fuscogilva*), black teatfish (*Holothuria nobilis*), elephant's trunkfish (*Holothuria fuscopunctata*) and prickly redfish (*Thelanota ananas*).

At each site, two teams of divers each laid their transect line three times to count and measure sea cucumbers and pearl oysters, giving a total of six counts per site (Plates 5 - 8). Each transect was 50 m long (defined by the tape measure) and 5 m wide. Transects of a different size were used to sample the deep habitat since the density of invertebrates differed between habitats and larger transects were required to obtain precise estimates of abundance in the deep habitat. Transect width was defined by two divers who swam parallel to each other holding on to either end of an extended 5†m length of rope. Each team of divers consisted of one diver who counted and measured invertebrates and another diver who laid and retrieved the transects. Invertebrates were measured as described in the previous section. Animals outside the transects were also measured if time permitted.

4.1.2.3 STATISTICAL ANALYSIS OF DATA

4.1.2.3.1 Abundance of invertebrates

The abundance of invertebrates was compared at three times before and three times after the establishment of the MCA and across three spatial scales using asymmetrical analysis of variance (ANOVA) (Winer *et al.* 1991, Underwood 1993). The three spatial scales examined were <u>Groups</u>, which included the Arnavons and the three reference areas Waghena, Ysabel and Suavanao, <u>Islands</u> within each Group and <u>Sites</u> within each Group and Island. Sites were the individual places where transects were laid. Separate analyses were done for the shallow and deep habitats because different species of invertebrates generally occurred between depths and different survey methods were used. The factors examined using asymmetrical ANOVA are summarised as follows:

- Before vs After, which was considered orthogonal and fixed.
- Times, which was nested within Before vs After and was random.
- Groups, which was considered a random factor and included a comparison of the Arnavon Islands with the three reference groups (the asymmetrical component) and a comparison among the three reference groups. Groups was orthogonal with respect to Before vs After and Times.
- Islands, which was nested within Groups, was orthogonal to Before vs After and Times and was a random factor. There were two Islands within each group.
- Sites which was nested within Islands and Groups, was orthogonal to Before vs After and Times and was a random factor. There were four sites sampled for each habitat within each Island and Group.

Six replicate transects were laid haphazardly within each site. Sources of variation in the abundance of invertebrates were partitioned, mean squares were calculated, and appropriate tests created according to Underwood (1993).

The study incorporated two temporal and three spatial scales. The establishment of the MCA may have had an effect on the abundance of invertebrates at a variety of temporal and spatial scales. Consequently, there were several ways that an effect of the establishment of the MCA may have been detected. In general, the MCA could have been shown to be effective if there was an increase in the abundance of invertebrates from before to after (or among times within before and after) the establishment of the MCA at the Arnavon Islands and no corresponding increase in abundance at the reference groups. Alternatively, the MCA could have been considered effective if there was no change in abundances within the MCA, but declines in abundances in the reference areas. These could be demonstrated by specific combinations of significant and non-significant temporal and spatial interaction terms.

There were no tests available for some terms but sometimes tests could be created by eliminating appropriate interactions that were non-significant at p(0.25 (Winer *et al.* 1991). The assumption of homogeneity of variance was tested prior to analysis using Cochran's C test. Attempts were made to stabilise heteroscedastic data by using a ln(x+1) transformation but if transformation failed to stabilise variances, untransformed data were used in the analyses. Analysis of heterogeneous data was considered acceptable since ANOVA is robust to violation of this assumption, particularly if data are balanced and sample sizes are large (Underwood 1997), as was the case in this study. Post-hoc SNK tests were done whneever significant tests were found to determine where the differences occurred.

4.1.2.3.2 Sizes of Invertebrates

Sizes of invertebrates were investigated using a combination of ANOVA and size frequency graphs. Due to the complex nature of the experimental design, variation in mean sizes was analysed using ANOVA. Different numbers of animals were measured at each site and time, but ANOVA should only be done on balanced designs (i.e. the same number of replicates in each treatment; Underwood 1997). The number of replicates available, therefore, was limited by the minimum number of animals measured in any one treatment. In all cases, there were too few measurements made to enable comparison across all temporal and spatial scales. For example, often less than 10 animals were measured in a treatment and this sample size was considered too small to accurately represent the mean size of the population at that place and time. Data were pooled, therefore, across spatial and/or temporal scales to increase the number of replicates available. Where necessary, equal numbers of replicates were achieved by randomly eliminating data. Two designs were used, depending on the number of animals available after pooling.

Design 1 was used for analysis of sizes of trochus (n = 33) in the shallow habitat, and for lollyfish (n = 69), white teatfish (n = 35) and elephant trunkfish (n = 40) in the deep habitat. Measurements were pooled across sites and islands within the Arnavons and across sites, islands and groups within the reference groups. Measurements were also pooled across all three times sampled before and three times sampled after the establishment of the MCA. Sizes were then compared between the Arnavons and reference groups, from before to after the establishment of the MCA using a two-factor ANOVA. The factors were <u>Before vs After</u> and <u>Arnavons vs references</u>. Both factors were fixed. Cochran's tests were used, prior to analyses, to test the assumption of homogeneity of variances. If variances were heterogeneous then appropriate transformations were performed. For the analysis of trochus, variances could not be stabilised, so analyses were performed on untransformed data.

More measurements were made for *Tridacna maxima* in the shallow habitat, hence it was possible to compare sizes of this clam using asymmetrical ANOVA (Design 2). Data were pooled across sites and islands within both the Arnavons and reference groups. The number of replicates (n) used was 47. The factors analysed were:

- Before vs After, which was considered fixed and orthogonal.
- Times which was nested within Before vs After and was a random factor.
- Groups, which included a comparison of the Arnavon Islands with the three reference groups

(i.e. the asymmetrical component) and a comparison among reference groups. Groups was a random factor and was orthogonal with respect to Before vs After and Times.

All data on sizes were transformed to ln(x+1) prior to analysis.

Where the results were consistent with the MCA influencing sizes (e.g. significant "Before vs After" x "Arnavon vs References" interactions), size frequency histograms were plotted to aid in interpreting the nature of the changes. Size frequency histograms were plotted using all available data.

4.1.3 Results

Four categories of general results were observed for abundances of invertebrates.

1) Numbers increased at the Arnavons from before to after the declaration of the MCA and numbers remained similar, or declined at the reference locations. This was observed for *Trochus niloticus* and for white teatfish. These results indicated that the establishment of the MCA had caused an increase in the number of commercially important invertebrates of these species.
2) Numbers remained similar at the Arnavons from before to after the declaration of the MCA, but numbers declined at the reference locations. This was observed for total holothurians in the deep habitat and, although not conclusive, there was some evidence for this trend for amberfish. This indicated lack of recruitment during the study and the ongoing effects of harvesting of these species at the reference areas (i.e. where fishing was not prohibited).
3) Similar changes in abundance occurred at both the MCA and reference locations from before to after the declaration of the MCA. This was observed for all giant clams combined, *Tridacna maxima* and greenfish in the shallow habitat and for elephant's trunkfish in the deep habitat. This indicated no effect of the MCA for these species.
4) Numbers remained similar at the Arnavon Islands and increased at the reference locations from before to after the declaration of the MCA. This was observed for *Tectus pyramis*, the only non-commercial species examined. This finding is difficult to interpret, but the trend may be due to less competition for space between *Tectus* and *Trochus* at reference areas, due to the small numbers of the latter.

Results of size analyses were varied. The mean size of *Trochus niloticus* increased after the declaration of the MCA, however the mean size of white teatfish decreased, due to recruitment of small individuals into the population. The MCA appeared to have no effect on sizes of other species.

Results for each variable analysed are discussed in detail in the following sections.

4.1.3.1 INVERTEBRATES IN THE SHALLOW HABITAT

4.1.3.1.1 Abundance

Trochus niloticus

The establishment of the MCA caused an increase in the abundance of *Trochus niloticus* (Table 2, Fig. 2a). There was a three-fold increase in the number of *T. niloticus* at the Arnavon Islands from before to after the establishment of the MCA, but numbers remained similar at the reference groups over the same time period. There was no test available for variation among islands (Table 2), however, examination of Figure 2b suggests that there was an increase in the number of *T. niloticus* at both of the Arnavon islands, but numbers remained similar, or decreased at all but one of the reference islands (Fig. 2b). The abundance of *T. niloticus* also increased at the scale of sites (Table 2). SNK analyses indicated that numbers increased substantially at two sites within the MCA but remained similar at the reference sites from before to after the declaration of the MCA (Table 2, Figure 2c).

Tectus pyramis

The abundance of *Tectus pyramis* remained unchanged from before to after the establishment of the MCA at the Arnavon Islands. At the 24 reference sites, however, abundances increased at 11 sites, decreased at 2 sites and remained unchanged at 11 sites (Fig. 3c). The observation that numbers decreased at 2 sites and remained unchanged at 11 sites (Fig. 3c). The observation that numbers increased at almost half of the reference sites, but remained unchanged at all of the MCA sites indicates that the MCA may have inhibited increases in abundances observed at many sites outside the marine conservation area.

Total giant clams

The MCA had no effect on the abundance of clams (Table 4). The abundance of clams almost doubled from before to after the declaration of the MCA but increases occurred at both the MCA and the reference groups (Fig. 4). Consequently, the increase in the number of clams could not be attributed to the establishment of the MCA. The increase in the number of clams appeared to occur at the scales of groups, islands and at the majority of sites (Figs. 4a,b,c), although the magnitude of the increase was not consistent among reference sites (Fig. 4b)

Tridacna maxima

The MCA had no effect on the abundance of *T. maxima* (Table 5). There was a general increase in the abundance of *T. maxima* with numbers increasing at 7 of the 8 sites within the MCA and at 20 of the 24 reference sites (Fig. 5c). Since similar variation was observed at both the MCA sites and reference sites, the increase in abundance cannot be attributed to the establishment of the MCA.

Total holothurians - shallow habitat

The establishment of the MCA had no effect on the abundance of holothurians in the shallow habitat (Table 6). Examination of Fig. 6, however, suggested that abundances almost doubled at the Arnavon group from before to after the establishment of the MCA, but remained similar the reference groups. The test to detect changes at the MCA relative to reference groups (B x MCA vs References interaction) had few degrees of freedom and the power of the test was probably too low to identify the trend. There was temporal variation in the abundance of holothurians among Arnavon sites after the establishment of the MCA, however, temporal variation after the establishment of the MCA did not differ from temporal variation before the establishment of the MCA and was not attributable, therefore, to the MCA (Table 6).

Greenfish

The establishment of the MCA had no effect on the abundance of greenfish (Table 7). Abundances varied among sites at the Arnavon group after the establishment of the MCA but remained similar at the reference sites (Figure 7). SNK analysis indicated that the variation was caused by a decrease in abundance of greenfish at one site at the Arnavon Islands. The establishment of the MCA, therefore, had no effect on numbers of greenfish. During the field studies we did observe large numbers of green fish in parts of the MCA but away from the study sites. These included some very shallow areas of reef terrace (<0.3 m), particularly at the entrances to narrow embayments and lagoons. The abundance of greenfish was low compared with the other species of invertebrates sampled (less than 0.2 animals per $100m^2$) and greenfish were found at only one site at Waghena and at no sites at Suavanao during the study. None were observed outside the study sites within the reference areas.

4.1.3.1.2 Sizes of invertebrates in the shallow habitat

The MCA had no effect on the size of *Tridacna maxima* (Table 8). There were, however, differences in the mean size of *T. maxima* among groups, with the mean size of clams being largest at the Arnavon Islands and smallest at Waghena (Fig. 8a). There was also variation in the mean size of clams among times sampled before and after the declaration of the MCA (Fig. 8b).

The mean size of *Trochus niloticus* increased at the Arnavons and decreased at the reference locations from before to after the declaration of the MCA (Fig. 9, Table 9). This result was consistent with the MCA causing an increase in the mean size of individuals. Examination of size frequency histograms for the Arnavon group and reference groups, before and after the establishment of the MCA indicated that there was a shift towards larger size classes at the Arnavon group. Interestingly, despite large increases in abundances, there was no evidence of small recruits entering the population, possibly due to the cryptic habits of juveniles and associated difficulty in detecting them. Alternatively, juveniles may settle into habitats away from the study sites.

4.1.3.2 INVERTEBRATES IN THE DEEP HABITAT

4.1.3.2.1 Abundance

Total holothurians

The establishment of the MCA did not cause abundances of holothurians in the deep habitat to increase, however, it appeared to prevent further declines in abundances occurring in the region. SNK analyses indicated that the abundance of holothurians remained similar at the Arnavon group from before to after the declaration of the MCA, but declined, on average, by approximately one third at the reference groups (Table 10, Fig. 10). The effect was also observed at the scale of sites. There was no variation in abundances among sites at the Arnavon group from before to after the establishment of the MCA. At the reference sites, however, abundances declined at 11 sites, increased at one site and remained unchanged at 12 sites. This suggests that the MCA was effective at maintaining population levels, but ineffective at enhancing abundances.

White teatfish

The establishment of the MCA did affect abundances of white teatfish which differed between the Arnavon group and the reference groups from before to after the establishment of the MCA (Table 11). SNK tests failed to identify where the differences occurred, largely due to the small number of degrees of freedom associated with the test. Examination of the Fig. 11a, however, suggests that abundances doubled at the Arnavon group and decreased by up to 90% at the reference groups from before to after establishment of the MCA. This trend was more easily identified at the scale of sites (Fig. 11b). Abundances increased greatly at 2 sites at the Arnavon group and decreased at four sites at the reference groups. Abundances at all other sites remained unchanged. Although the number of sites where differences occurred was small, the direction of the trends suggested that the MCA had an effect in increasing abundances at some sites at the Arnavon group and preventing further declines in abundances apparent at some sites at the reference areas.

Lollyfish

The declaration of the MCA had no effect on the abundance of lollyfish (Table 12). Lollyfish were most abundant at the MCA, but patterns of abundance among groups did not change from before to after declaration (Fig.12). Moreover, no small-scale effects were detectee between islands or among sites (Table 12). Some short-term temporal variation was observed at the Arnavon group following declaration, but similar variation was also observed before the MCA was established, indicating that it was not caused by the MCA (Table 12). Similarly, short-term temporal variation was identified among sites within the Arnavon Group after the declaration of the MCA. This variation was inconsistent from before to after the declaration of the MCA but similar differences in temporal variation were observed at the reference sites, indicating the MCA did not cause this temporal variation.

Amberfish

The establishment of the MCA had no effect on abundances of amberfish at the scale of groups (Table 13). There was some evidence, however, to suggest that the MCA may have prevented further declines in abundance from occuring at some sites. There was no change in abundance at all sites in the Arnavon group, however, SNK tests indicated that abundance decreased at four of the reference sites, remained unchanged at 19 sites and increased at one site (Fig. 13). Although the evidence is not strong, it does indicate that the establishment of the MCA may have had some role in preventing declines in this species at the Arnavon group.

Elephant trunkfish

The declaration of the MCA had no effect on the abundance of elephant trunkfish (Table 14). Abundances increased at one site within the Arnavon group after the establishment of the MCA (Table 14, Fig. 14), however similar variation was observed among reference sites indicating that the MCA had no effect at the scale of sites (Fig. 14).

4.1.3.2.2 Sizes of invertebrates in the deep habitat

The MCA had no effect on the sizes of lollyfish or elephant trunkfish (Table 15). There were differences in the mean sizes of lollyfish (Fig. 15a) and elephant trunkfish (Fig. 15b) between the MCA and reference areas. Lollyfish were larger at the reference areas, but elephant trunkfish were larger at the MCA.

The mean size of white teatfish varied between the MCA and reference areas from before to after the declaration (Table 15). The mean size of white teatfish increased at the reference areas, and decreased at the MCA (Fig. 15c). Examination of the size frequency distributions (Fig. 15d) indicated that the decrease in size at the Arnavon group was probably due to recruitment of small holothurians into the population after the establishment of the MCA. In contrast, there were few small holothurians at the reference areas after the declaration of the MCA and the mode of the population had increased, probably due to growth of the population.

4.1.4 Importance of the Results

The findings of the study are of great importance at a local and international scale. In particular, the study has developed and applied a methodology that can be used to evaluate the success of marine reserves through "baseline" comparisons with multiple appropriate reference areas.

The results show that some species increased in abundance in the MCA over time while others did not, suggesting that there is considerable variability in the response of invertebrates to the removal of fishing pressure. The results also show that estimates of recovery can depend on the actual sites surveyed within the MCA. This suggests that effective monitoring of marine reserves will depend on sampling a large number of sites within the protected area. In this study, four sites were sampled at each of the two islands within each group. The sensitivity of the monitoring program to detecting increases in abundance in the MCA would be improved by expanding the number of sites to provide a better measure of variability within the MCA (see below).

The results also show that local communities can use closures as short as three years to help manage stocks of trochus, since trochus populations increased in both number and size within this time frame. This suggests that a management plan could be initiated for trochus throughout the Solomon Islands in which some reefs are closed for long enough to ensure that they have large stocks. Others areas would be harvested and then closed for three years on a rotational basis to provide sustainable production. It also helps to vindicate the decisions made by the local management committee in supporting the declaration of the MCA.

Notwithstanding the results of the study, it should be noted that, although significant differences were detected, the actual increases of animals in terms of numbers per hectare remained low relative to what may be expected within the region (Table 16). For example, three years after the establishment of the MCA, densities of *Holothuria fuscogilva* were estimated at 16 ha-1 which was within the range compared with other fished areas in the Pacific, but was much lower than maximum density estimates of 82 ha^{-1} observed in Tonga. Similarly, Although abundances of *T. niloticus* increased to approximately 57 ha^{-1}, this was also well below estimates of densities from other areas (62-2016 ha-1; Table 16). This indicates just how heavily over-exploited the stocks were at the beginning of the study and how long it may take stocks to recover to densities recorded elsewhere in the region.

4.2 Travel and Meetings During the Final Year

Travel by Dr Marcus Lincoln Smith during the final year included participation in the first of the series of the final three surveys designed to provide the data for statistical comparison with the data collected prior to declaration of the MCA. In addition, Mr Peter Ramohia, a Scientific Officer from the Solomon Islands Fisheries Division traveled to Sydney for training in statistical analysis of the survey data and the preparation of scientific publications. The outcome of this visit is discussed in more detail below.

4.3 Budget Discussion

The budget was adequate for the study but it was slightly overspent. The additional costs were borne by ICLARM. An extra budgetary item was the visit by Peter Ramohia to Sydney in June 1999. This trip was covered by a separate allocation of funds from ACIAR.

One minor budgetary problem encountered was that there were some unforeseen costs in the operation of the research vessel, *Daula*, due to increases in seagoing allowances. Such increases should be included in the budget for any continuation of the monitoring. Copies of the budgetary expenditure on the project by The Ecology Lab and ICLARM are provided separately.

4.4 Conclusions

The project set out to examine the effectiveness of marine reserves using the MCA as a case study. The study design included the use of data from before and after declaration at both the MCA and reference groups. All the sampling was completed successfully in the context of the original objectives, and every required sample was taken. This represents a major achievement in terms of organisation and implementation.

The outcomes of the study provide encouraging results for the restoration of populations of trochus, but it appears that a substantial recovery time may be required for this species within the MCA and even longer duration for other species, including some sea cucumbers and giant clams. Consequently, the closure on harvesting at the MCA should continue and there should be additional monitoring, using the same general approaches as developed for the shallow and deep habitats.

Another important finding was that recovery tended to occur at small spatial scales within the MCA. Thus, larger increases in trochus (and some encouraging increases for other species), occurred at only some sites, while other sites showed little or no increase. Some of these results may be due to poaching (see Section 5), however, others can be explained by, patchy recruitment within the MCA, or by differences in habitat that were not readily apparent during site selection. A primary goal of future monitoring should be to observe if those sites in the MCA with fewer invertebrates show a significant increase in abundance over a longer time. In the longer term, if recovery does not increase in the MCA, this in itself will be important for the management of fisheries based on tropical invertebrates. For example, it might suggest management alternatives such as re-stocking or broader limits on size or seasonal harvesting within the region.

A closure on the harvesting of trochus within the MCA has lead to an increase in the size of trochus, consequently use of a rotational closure will not only enhance abundances of trochus, but it will also increase the yield per animal harvested. Although mean sizes of white teat fish declined, this was largely due to recruitment of small animals into the population.

An important advantage of the statistical procedure used for this study is that additional surveys can be readily incorporated into the analysis of data. The analysis used here included factors for Times (Before) vs Times (After), with three surveys within each Time. This could now be expanded readily to include Times (Before) vs Times (After 3 yrs) vs Times (After 6 yrs). This would require collection of data on three occasions approximately 6 years after declaration of the MCA.

5.0 RESEARCH RESULTS AND OUTCOMES

5.1 Progress of Research Work for the Projectís Lifetime

The progress of research was generally as planned through the project, with suitable time allocated for planning and preparation of each field trip. The methods developed worked well and would be suitable for continued studies in the area. Given that the species and habitats studied occur throughout the tropical Pacific and Indian Oceans, the methods developed would be adaptable to studies elsewhere. Moreover, the sampling equipment is simple and inexpensive, increasing its applicability for use in developing nations.

As in any large study, some problems were encountered. These were generally limited to poor weather at times, occasional mechanical problems (e.g. with the air compressor and the Daula) and some staff illness (e.g. malaria). However, no major logistical problems occurred throughout the project and the necessary sampling was always completed.

The most serious research problem encountered was the illegal taking of invertebrates within the MCA. Several incidents of poaching were reported by the COs and some animals were confiscated and returned to the water. It appears that the only species targeted was trochus. Clearly if poaching continues, it will threaten the success of the MCA and the monitoring program. TNC have made concerted efforts to address this problem and have recently succeeded in prosecuting those involved (Appendix 1). Poaching appears to have been limited to a minority of sites in the MCA which means that long term monitoring is still valid.

As discussed in Section 7, several reports have been prepared for the project and one scientific paper published in the Proceedings of the 8th International Coral Reef Symposium. The paper focused on the design of the study and presented the results of the surveys prior to declaration of the MCA. Two other papers are being prepared. One addresses management issues and will be submitted to *NAGA* in 2000. The other paper is a more complete statistical analysis and detailed interpretation of results. It will be submitted to an international journal by mid-2000. Aspects of the findings of the study will be presented at the 9th International Coral Reef Symposium and published in the proceedings.

5.2 Impact and Future Directions of the Project

There are several major impacts of the project. These are:

1) Involvement of communities - the local communities have shown a strong interest in the project and an appreciation of the role of the MCA. Presentations of information at annual visits to villages in the area have been well attended and engendered thoughtful discussions.
2) The Management Committee for the MCA has delayed it decision on extending the three year closure until the results of the study have come to hand.
3) The existence of a rigorous monitoring program has helped TNC to obtain additional funding for the Management Committee.
4) The MCA has been used by the Government of Solomon Islands as justification for planning the establishment of additional marine reserves.
5) The presentation of findings in the scientific literature has contributed to the general knowledge on the effectiveness of marine reserves, particularly in terms of designing rigorous monitoring programs to test their effectiveness. The manuscripts in preparation will make a similar contribution to our understanding of the recovery of harvested stocks and to protocols for managing marine reserves.

The findings of the study strongly support the continuation of the MCA and the monitoring program for marine invertebrates. Decisions about the duration of the fishing closure and continued monitoring should include the following considerations.

1) The fact that a considerable length of time may be needed to restore stocks, or to assess whether the MCA is effective for all species, especially holothurians.

2) The operation of the Management Committee. Arrangements must be made to ensure that it continues to operate and that it can deter poaching effectively.

3) The continued participation of the Division of Fisheries and use of the *Daula*.

6.0 USE OF RESULTS

It is expected that the results will be used to argue for continued maintenance of the Arnavon Islands MCA. Without some indication of success, it would be very difficult (and possibly unwarranted) to continue with the project, but at this stage, there are several benefits still to be achieved. These include obtaining further scientific information and application of the principals of the reserve to other areas. More specifically, the results should be used in the following ways:

1) By the Management Committee and TNC to extend the closure at the Arnavon Islands.

   By the Government of Solomon Islands to declare more marine reserves throughout the country, at least for trochus at this stage.

2) By ICLARM to demonstrate why a sampling design of the nature used here is necessary to demonstrate to Fisheries Departments of developing Indo-Pacific nations how to detect the effects of marine protected areas.

3) By the project scientists and Solomon Islands Fisheries Officers to prepare scientific papers on the findings of the study.

7.0 PUBLICATIONS AND REPORTS

One scientific paper has been published from the study and three others are in preparation. Several progress reports were also prepared during the study and a manual was produced for project staff outlining sampling locations and methods.

Scientific Paper

Lincoln Smith, M. P., Bell, J. D., and Mapstone, B. D. (1997). Testing the Use of a Marine Protected Area to Restore and Manage Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Choice of Methods and Preliminary Results. In: *Proceedings of the 8th International Coral Reefs Symposium, Panama*, 1996, Volume 2: 1937 - 1942.

Reports

Lincoln Smith, M. P. (1994). Testing the use of marine protected areas to restore and manage tropical multispecies invertebrate fisheries at the Arnavon Islands, Solomon Islands: report on pilot investigations. Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P. (1995). Arnavon Islands Survey Of Commercially Exploited Invertebrates: Field Manual And Pictorial Guide To Common Invertebrates Recorded. Unpublished report prepared by The Ecology Lab Pty Ltd, Sydney.

Lincoln Smith, M. P. and Bell, J. D. (1996). Testing the use of marine protected areas to restore and manage tropical multispecies invertebrate fisheries at the Arnavon Islands, Solomon Islands: Abundance and size frequency distributions of invertebrates, and the nature of habitats, prior to declaration of the Marine Conservation Area. Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P. (1996). Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Abundance of Invertebrates One Year After Declaration of the Marine

Conservation Area. Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P., Ramohia, P. and Astles, K. (1997). Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Abundance of Invertebrates Two Years After Declaration of the Marine Conservation Area. Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

8.0 FOLLOW-UP

There are three main areas that should be considered for follow-up ñ two of these are related to the studies at the Arnavon Islands, the third is related to expansion into other areas.

The first is to continue the present study at the MCA and reference areas, preferably for a further three years (with surveys in September 2001, September 2002, January 2003 and April 2003). This would enable us to measure possible further increases in the abundance of trochus in the MCA and, hopefully, to identify the time needed for recovery of several of the commercially important sea cucumbers.

Continuing the study under this framework would result in an almost continuous annual set of data from 1996 to 2003. This is important for monitoring recovery rates for commercially valuable species and is also important in maintaining the enthusiasm and interest of local communities. The three surveys in September 2002 and January and April 2003 would also provide a third temporal component to the asymmetrical ANOVA, by enabling a comparison of pre-MCA with three years post-MCA and 6 years post-MCA. This would benefit the study in two ways. If recovery of species continues, then the magnitude of differences in abundance from before to six years after the establishment of the MCA will be larger and, therefore, easier to detect. Adding a second series of "After" surveys will also increase the statistical power of the design which should also increase our ability to detect an effect of the MCA. This would provide a very powerful basis for assessing the effectiveness of a marine reserve for marine invertebrates.

The second area of follow-up is to commit extra resources to sampling additional sites within the MCA. This is because there was great variability in rates of recovery among sites and it would be useful to determine whether the variation observed among sites encompassed the range of variability within the MCA. Moreover, field observations suggested that other sites within the MCA may be more favourable to some species, such as greenfish (Section 4.1.3.1.1). Therefore, there may be some sites within the MCA which experienced even greater rates of recovery than were measured in this study. These data would augment data collected in the current study but would not be included in the main asymmetrical analysis. Sampling of additional sites should be done in a quantitative manner, however, to enable rigorous comparison of abundances among sites. Previously, eight sites were sampled in each habitat within the MCA. It is recommended that sampling be done in a further eight sites within the MCA in September of 2001, 2002 and 2003.

These two areas of follow-up both need the support of the local communities and would require that harvesting of marine invertebrates in the MCA continue to be prohibited. It also requires continued use of Conservation Officers to patrol and monitor activities within the MCA. In order to facilitate this, TNC and the Government of Solomon Islands would need to maintain their support for the project.

The third area of follow-up involves disseminating the results of the study to other areas of the country and elsewhere in the region. During the study, some of the local communities expressed interest in setting aside other coral reefs as marine reserves. The Arnavons MCA could form the nucleus and/or model for a series of marine reserves within the region, which, in turn, could be a valuable experience applicable to other nations in the tropical Pacific. The best approach for achieving this will be to ensure that appropriate scientific and managerial rigour are applied to any further reserves and that the findings of the present study are properly disseminated. This component of the follow-up would, therefore, require project staff to visit other sites to inform stakeholders of the benefits of the MCA and to assist them to implement well designed monitoring programs. In relation to this, it is interesting to note that the Government of Solomon Islands, in collaboration with the Asian Development Bank, is applying for funding from the Global Environment Facility (GEF) to increase the number of marine protected areas in the country.

9.0 TRAINING AND CAPACITY BUILDING

Training of Solomon Island participants occurred at a number of levels. First, Conservation Officers, and Scientific Officers from Fisheries Division, were trained to SCUBA dive and to conduct underwater visual census of invertebrates. Important components of this training included:

- field preparation,
- diver safety (including code of practice provided by ICLARM),
- species identification, and measurement of specimens underwater,
- deployment of transects underwater, ensuring that:
    - appropriate habitat was sampled, and
    - biases were not introduced by non-random allocation of the transect lines,
- transcription of data from slates to data sheets and checking of results,
- ensuring the security of the data.

During the first few surveys, time was allocated at the beginning of each trip for training, and then later for revision of methods. One very important aspect of training was to ensure that all those participating in the surveys understood the importance of collecting data for all the required transects (i.e. sample replicates). It is particularly pleasing to note that, for the total of 3,072 replicates required for the entire study, not a single replicate was missed, or one data sheet lost. This is a strong indicator of the conscientious attitude and enthusiasm of the participants.

Second, Mr Peter Ramohia visited Sydney in June 1999 as part of a training exercise. The specific aims of the trip were to:

- assist with computer entry and data checking for the last three surveys,
- prepare a manuscript for submission to the ICLARM journal NAGA, with emphasis on management issues associated with the study, and
- visit ACIAR offices in Sydney and tour facilities at the NSW Fisheries Research Institute and the University of Sydney.

Capacity building was evident in the way that the Solomon Island participants and ICLARM were able to plan and conduct four of the surveys without direct attendance of the Project Scientist. This was achieved by training of staff and by providing a specific itinerary for each field trip, which included a day-by-date schedule of sampling, the most efficient routes of travel to the sites and a suitable number of rest days.

At the request of TNC, the Project Scientist and Fisheries Officers visited four local communities to present information on the study during the last two surveys. The focus of these presentations was on the general importance of the study, sampling methods, preliminary results and management issues. During every visit there was a large attendance (usually 20 to 100 people) and numerous questions were asked. Whilst not strictly "training", this aspect of the study was an important means of maintaining local interest in the study.

10.0 ACKNOWLEDGEMENTS

The success of this project is due to the diligence and enthusiasm of many individuals and organisations (Plate 9). Without their contribution the final outcome would have been far less impressive. The contributions of the following require special mention:

1) Members of the MCA Management Committee, who guided the project in the region and provided continuous support through the study and enabled us to stay at a variety of islands/villages during the field work.
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11.0 REFERENCES

Babcock, R. C., Kelly, S., Shears, N. T., Walker, J. W. and Willis, T. J. (1999). Changes in community structure in temperate marine reserves. *Marine Ecology Progress Series, 189*: 125-134.

Ballantine, B. (1991). *Marine Reserves for New Zealand.* University of Auckland, Auckland, NZ, 196 pp.

Bergin, T. (1993). Marine and Estuarine Protected Areas (MEPAs)- Where Did Australia Get It Wrong? *In: Protection of marine and estuarine areas - a challenge for Australians: Proceedings of the fourth Fenner conference on the environment*, Ivanovici, A. M.; Tarte, D., and Olson, M., (eds). Australian Committee for IUCN, Canberra. pp. 148-155.

Bohnsack, J.A. (1993). Marine Reserves: They Enhance Fisheries, Reduce Conflicts, and Protect Resources. *Oceanus* pp. 63-74.

Carr, M.H. and Reed, D.C. (1993). Conceptual issues relevant to marine harvest refuges - examples from temperate reef fishes. *Canadian Journal of Fisheries and Aquatic Sciences* **50**, pp. 2019-2028.

Cole, R. G., Ayling, A. M. and Creese, R. G. (1990). Effects of marine reserve protection at Goat Island, northern New Zealand. *New Zealand Journal of Marine and Freshwater Research,* **24**: 197ñ210.

De Martini, E.E. (1993). Modelling the potential of fishery reserves for managing pacific coral reef fishes. *Fishery Bulletin* **91**, pp. 414-427.

Dugan, J.E. and Davis, G.E. (1993). Applications of marine refugia to coastal fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences* 50, pp. 2029-2042.

Ferreira, B.P. and Russ, G.R. (1995). Population structure of the leopard coral grouper, *Plectropomus leopardus,* on fished and unfished reefs off Townsville, Central Great Barrier Reef, Australia. *Fishery Bulletin* **93**, pp. 629-642.

Holland, A. (1994). The sea cucumber industry in Solomon Islands: recent trends and suggestions for management. *SPC Beche-de-Mer Information Bulletin,* **6**: 2-9.

Ivanovici, A. M., Tarte, D. and Olson, M (Eds). (1993). *Protection of marine and estuarine areas ñ a challenge for all Australians.* Proceedings of the Fourth Fenner Conference on the Environment, Canberra, 9 ñ 11 October, 1991. Occasional Paper No. 4, Australian Committee for IUCN, Sydney, Australia.

Kelly, S., Scott, D., MacDiarmid, A. B. and Babcock, R. C. (2000). Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. *Biological Conservation,* **92**: 359-369.

Kenchington, R. and Bleakley, C. (1994). Identifying priorities for marine protected areas in the insular Pacific. *Marine Pollution Bulletin* **29**, pp. 3-9.

Lincoln Smith, M. P. (1994). *Testing the use of marine protected areas to restore and manage tropical multispecies invertebrate fisheries at the Arnavon Islands, Solomon Islands: report on pilot investigations.* Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P. (1996). *Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Abundance of Invertebrates One Year After Declaration of the Marine Conservation Area.* Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P. and Bell, J. D. (1996). *Testing the use of marine protected areas to restore and manage tropical multispecies invertebrate fisheries at the Arnavon Islands, Solomon Islands: Abundance and size frequency distributions of invertebrates, and the nature of habitats, prior to declaration of the Marine Conservation Area.* Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Lincoln Smith, M. P., Bell, J. D., and Mapstone, B. D. (1997). Testing the Use of a Marine Protected Area to Restore and Manage Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Choice of Methods and Preliminary Results. In: *Proceedings of the 8th International Coral Reefs Symposium, Panama*, 1996, Volume 2: 1937 - 1942.

Lincoln Smith, M. P., Ramohia, P. and Astles, K. (1997). *Testing the Use of Marine Protected Areas to Restore and Manage Tropical Multispecies Invertebrate Fisheries at the Arnavon Islands, Solomon Islands: Abundance of Invertebrates Two Years After Declaration of the Marine Conservation Area.* Prepared for Great Barrier Reef Marine Park Authority, Canberra and the Australian Centre for International Agricultural Research, Sydney.

Long, B.G., Poiner, I.R. and Harris, A.N.M. (1993). Method of estimating the standing stock of *Trochus niloticus* incorporating Landsat satellite data, with application to the trochus resources of the Bourke Isles, Torres Strait, Australia. *Marine Biology* **115**, pp. 587-593.

McClanahan, T.R. (1995). A coral reef ecosystem-fisheries model - impacts of fishing intensity and catch selection on reef structure and processes. *Ecological Modelling* **80**, pp. 1-19.

Munro, J.L. (1993). Giant clams. In: Wright,†A. and Hill, L. (eds). *Nearshore Marine Resources of the South Pacific*. pp. 431-450.

Nash W.J., Tuara, P., Terekia, O., Munro, D., Amos, M., Legata, J., Mataiti, N., Teopa, M., Whitford, J. and Adams, T. (1995). The Aitutaki trochus fishery: a case study. South Pacific Commission Inshore Fisheries Research Project Technical Document No. 9. 72pp.

Parrish, R. (1999). Marine reserves for fisheries management: Why not. *CalCOFl Report*, Volume **40**, 1999: 77-86.

Preston G. (1993). Beche-de-Mer. In: Wright,†A. and Hill, L. (eds). *Nearshore Marine Resources of the South Pacific*. pp. 371-408.

Richards, A.H., Bell, L.J., and Bell, J.D. (1994). Inshore fisheries resources of Solomon Islands. *Marine Pollution Bulletin* **29**, pp. 90-98.

Roberts, C.M. (1995). Rapid build-up of fish biomass in a Caribbean marine reserve. *Conservation Biology* **9**, pp. 815-826.

Roberts, C.M. and Polunin, N.V.C. (1991). Are marine reserves effective in management of reef fisheries? *Reviews in Fish Biology and Fisheries* **1**, pp. 65-91.

Roberts, C.M. and Polunin, N.V.C. (1993). Marine reserves: simple solutions to managing complex fisheries? *Ambio* **22**, pp. 363-368.

Russ, G.R. and Alcala, A. C. (1989). Effects of intense fishing pressure on an assemblage of coral reef fishes . *Marine Ecology Progress Series* **56**, pp. 13-27.

Sladek Nowlis, J. and Roberts, C. M. (1997). You can have your fish and eat it too: theoretical approaches to marine reserve design. In: *Proceedings of the 8th International Coral Reefs Symposium, Panama*, 1996, **2**: 1907 - 1910.

Sladek Nowlis, J. and Roberts, C. M. (1999). Fisheries benefits and optimal design of marine reserves. *Fisheries Bulletin*, **97**: 604-616.

Tsutsui, I. and Sigrah, R. (1994). Natural broodstock resources in Kosrae, Federated States of Micronesia. *South Pacific Commission Trochus Information Bulletin*, **3**: pp: 9-11.

Underwood, A.J. (1989). The analysis of stress in natural populations. *Biological Journal of the Linnean Society* **37**, pp. 51-78.

Underwood, A. J. (1991). Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research*, **42**: 569-587.

Underwood, A.J. (1993). The Mechanics of Spatially Replicated Sampling Programmes to Detect Environmental Impacts in a Variable World. *Australian Journal of Ecology* **18**, pp. 99-116.

Underwood, A.J. (1997). *Experiments in Ecology, Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge University Press, UK, 504 pp.

Watson, M. and Ormond, R.F.G. (1994). Effect of an artisanal fishery on the fish and urchin populations of a Kenyan coral reef. *Marine Ecology Progress Series* **109**, pp. 115-129.

Winer, B.J., Brown, D.R., and Michels, K.M. (1991). *Statistical Principles in Experimental Design*. McGraw-Hill, New York, USA, 1057 pp.

TABLES

Table 1. Description of sampling sites at the Arnavon Islands and Reference Groups. Latitudes and Longitudes measured using a hand-held Global Positioning System (GPS).

a) Sites sampled in the shollow habitat

Group	Island	Site	Latitude (South)	Longitude (East)	Site description
Waghena	1	**S1**	7o 31' 05"	157o 43' 48"	Ondolou Is. - reef shelf on eastern side of beach
		S2	7o 31' 13"	157o 43' 02"	Sunda Is. - reef shelf on southern side of island, just around from the beach
		S3	7o 32' 26"	157o 42' 46"	Ghire Is. - reef shelf off western end of island, near small sand spit
		S4	7o 30' 55"	157o 43' 16"	Sunda Is. - narrow reef shelf on northeastern side of island
	2	**S5**	7o 28' 56"	157o 49' 37"	Wagina Is. - western-most site, directly offshore of small, undercut rock island, inshore of D5. Site on outer edge of terrace
		S6	7o 29' 04"	157o 50' 09"	Wagina Is. - offshore of f western tip of island with long sandy beach; inshore of D6. Site on outer edge of terrace
		S7	7o 29' 19"	157o 50' 43"	Wagina Is. - just to the west of small island with clumps of mangroves, on outer edge of terrace. Inshore of D6
		S8	7o 29' 15"	157o 51' 00"	Wagina Is. - eastern-most site, to the east of small island with mangroves, outer edge of terrace.
Arnavons	3	**S9**	7o 26' 54"	157o 59' 14"	Sikopo Is. - corner of shoreline to the east of island - behind large reef break (bommie)
		S10	7o 26' 35"	157o 58' 59"	Sikopo Is. - narrow terrace on southern side of entrance to embayment
		S11	7o 26' 16"	157o 58' 59"	Sikopo Is. - shallow narrow terrace on northeastern tip of embayment. Surf often breaks here
		S12	7o 27' 18"	157o 59' 38"	Sikopo Is. - wide terrace to the east of small island along shoreline towards the end of the island. Site adjacent to entrance to small lagoon
	4	**S13**	7o 28' 13"	158o 03' 03"	Kerehikapa Is. - outer edge of reef terrace to the northwest of Little Maleivona Is
		S14	7o29' 09"	158o 02' 50"	Kerehikapa Is. - southwestern shore of Maleivona Is.
		S15	7o 28' 48"	158o 03' 02"	Kerehikapa Is. - northeastern end of Maleivona Is., near gap between Little Maleivona & Maleivona Iss.
		S16	7o 26' 58"	158o 02' 12"	Kerehikapa Is. - northern tip of Kerehikapa Is., middle of terrace (about 3 m deep)
Ysabel	5	**S17**	7o 22' 57"	158o 05' 52"	Sibau Is. - site on inner side of long reef extending northwest of Sibau Is., south of D17
		S18	7o 22' 45"	158o 05' 10"	Un-named reef - inner (sheltered) edge of isolated reef just offshore of passage between Pizuanakelekele Reef & Sibau Is.
		S19	7o 22' 00"	158o 04' 42"	Nohabuna Is. - sand/rubble habitat approximately 500 m south of the eastern tip of island
		S20	7o 22' 00"	158o 04' 39"	Nohabuna Is. - sand/coral/rubble habitat between Nohabuna and "Gilligan's" Iss., about 150 m offshore
	6	**S21**	7o 23' 25"	158o 09' 04"	Malakobi Is. - shallow coral terrace off island
		S22	7o 24' 01"	158o 09' 53"	Un-named reef - shallow terrace on southern side of isolated reek between Malakobi and Kologilo Iss.
		S23	7o 24' 01"	158o 09' 53"	Kologilo Is. - site on shallow terrace off wide intertidal rocky shore, northern side of island. Surveys done in 2-3 m water depth
		S24	7o 23' 57"	158o 09' 20"	Kologilo Is. - shallow terrace off western tip of island, inshore and just to the south of D24
Suavanao	7	**S25**	7o 36' 42"	158o 47' 22"	Pilena Faa Is. - shallow terrace at eastern end of island
		S26	7o 37' 15"	158o 47' 23"	Un-named reef - eastern end of shallow terrace on isolated reef to the south of Pilena Faa Is.
		S27	7o 36' 37"	158o 49' 43"	Repena Is. - outer tip of large, continuous reef
		S28	7o 35' 52"	158o 49' 52"	Repena Is. - outer tip of reef, approximately 1-2 km north of S27
	8	**S29**	7o 30' 21"	158o 42' 16"	Sogumau Is. - surveyed edge of coral terrace on reef at southern end of island
		S30	7o 29' 48"	158o 42' 30"	Sogumau Is. - spur-&-groove habitat approximately 1 km north of S29, opposite small clump of trees growing on reef flat
		S31	7o 29' 49"	158o 40' 15"	Un-named Is. - northern side of small islet located between two larger islets, in the bay to the northwest of campsite
		S32	7o 30' 25"	158o 39' 40"	Putuo Is. - southern side of island, just north of D31

Table 1, continued.

b) Sites sampled in the deep habitat

Group	Island	Site	Latitude (South)	Longitude (East)	Site description
Waghena	1	D1	7o 31' 06"	157o 43' 41"	Ondolou Is. - reef slope, begin at the middle of the beach; one team goes east, the other west
		D2	7o 30' 55"	157o 42' 57"	Sunda Is. - reef slope, begin at the middle of the beach; one team goes south, the other north
		D3	7o 32' 20"	157o 42' 46"	Ghire Is. - reef slope, northeastern end of the island, along the base of a large reef
		D4	7o 32' 18"	157o 42' 25"	Ghire Is. - northwestern end of island, directly off island, off small lean-to shelter
	2	D5	7o 28' 56"	157o 49' 37"	Wagina Is. - directly off small rock islet with large undercut at the waterline and topped with a few scraggy trees. Offshore of S5
		D6	7o 29' 07"	157o 50' 11"	Wagina Is. - offshore of f western tip of island with long sandy beach; offshore of S6.
		D7	7o 29' 18"	157o 50' 43"	Wagina Is. - to the west of clumps of mangrove; offshore of S7
		D8	7o 29' 16"	157o 50' 55"	Wagina Is. - eastern-most site, to the east of small island with mangroves, offshore, but slightly west of S8.
Arnavons	3	D9	7o 27' 21"	157o 59' 45"	Sikopo Is. - steep slope offshore and slightly east of S12
		D10	7o 27' 06"	157o 59' 26"	Sikopo Is. - west of D9, survey starts off the northwestern tip of small islet and runs towards the northwest
		D11	7o 26' 24"	157o 58' 46"	Sikopo Is. - northern shore of embayment where Daula moors, site runs from small cleared area to the entrance to the embayment.
		D12	7o 26' 25"	157o 59' 02"	Sikopo Is. - about 0.5 km west of D11, along theinner slope of the long narrow reef
	4	D13	7o 28' 13"	158o 02' 56"	Kerehikapa Is. - off Little Maleivona Is. along NW-SE stretch of reef
		D14	7o 28' 06"	158o 02' 40"	Kerehikapa Is. - directly offshore from "Rock Islet", between Little Maleivona & Kerehikapa Iss.
		D15	7o 27' 25"	158o 02' 15"	Kerehikapa Is. - inner slope of long finger reef, off northeastern tip of Kerehikapa Island
		D16	7o 27' 42"	158o 02' 38"	Kerehikapa Is. - inner slope of long reef, opposite the southeast tip of Kerehikapa Is.
Ysabel	5	D17	7o 22' 56"	158o 05' 56"	Sibau Is. - site on inner side of long reef extending northwest of Sibau Is., north of S17
		D18	7o 22' 58"	158o 06' 20"	Sibau Is. - northwestern end of island, approximately 150 m offshore
		D19	7o 22' 30"	158o 06' 45"	Un-named islet - northwestern side of small islet (has huts and was used by Gilbertese fishermen)
		D20	7o 23' 06"	158o 06' 35"	Sibau Is. - off northeastern end of island
	6	D21	7o 23' 30"	158o 08' 52"	Malakobi Is. - east-west running shoreline on the northern side of the bay where campsite located
		D22	7o 23' 09"	158o 09' 09"	Malakobi Is. - northern side of "finger" reef to the north of campsite
		D23	7o 22' 49"	158o 09' 19"	Pareipoga Is. - southern side of island, survey runs southeast-northwest
		D24	7o 23' 57"	158o 09' 20"	Kologilo Is. - slope off western tip of island, offshore and just to the north of S24
Suavanao	7	D25	7o 36' 32"	158o 47' 00"	Pilena Faa Is. - sand/rubble slope on nothern side of island
		D26	7o 36' 19"	158o 47' 57"	Katere Is. - southern shore, site located at first small point back from the southeastern end of the island
		D27	7o 34' 53"	158o 46' 00"	Papatura Ite Is. - northwestern end of beach, near first potential campsite
		D28	7o 36' 35"	158o 46' 36"	Un-named reef - reef has exposed sand bar; located between Pilena Faa and Pilena Ite Iss. Site on western side.
	8	D29	7o 29' 51"	158o 40' 54"	Vurongona Faa Is. - slope on southwestern side of island
		D30	7o 29' 53"	158o 40' 10"	Un-named Is. - inner (sheltered = southern) side of small islet near campsite; opposite side of islet to S31
		D31	7o 30' 27"	158o 39' 37"	Putuo Is. - southern side of island, just south of S32
		D32	7o 29' 58"	158o 39' 51"	Campsite - shoreline off lagoon to the south of campsite

Table 2. Asymmetrical ANOVA examining abundances of Trochus niloticus between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. "Before vs. after" is a fixed factor. M = MCA, R = References. "No test" = no appropriate MS denominator available to create F test. "Red." = redundant term due to significant lower-order interaction. Cochran's C = 0.1357, p<0.01.

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	1.8368	1.8368				Red	
T(B)	4	0.8576	0.2144				Red	
G	3	20.2569	6.7523				Red	
Gr(M)	1	8.1666	8.1666					
Gr(C)	2	12.0903	6.0452					
I(G)	4	4.9492	1.2373				Red	
I(G(M))	1	0.8889	0.8889					
I(G(C))	3	4.0903	1.3634					
S(I(G))	24	27.9306	1.1638				Red	
S(I(G(M)))	6	16.8334	2.8056					
S(I(G(C)))	18	11.0972	0.6165					
B x G	3	13.7951	4.5984	7.4613	0.0408	B x I(G)		
B x G(M)	1	11.8067	0.6163	19.1574	0.0119	B x I(G)	Variation at the MCA group, relative to reference groups, from before to after declaration	MCA has caused an increase in numbers at the scale of groups
B x G(C)	2	1.9884	0.9942	1.6132	0.3064	B x I(G)	No variation among reference groups from before to after declaration	
B x I(G)	4	2.4653	0.6163			No test		
B x I(G(M))	1	0.6806	0.6806			No test		
BA x I(G(M))	3	1.7847	0.5949			No test		
B x S(I(G))	24	26.6806	1.1117	2.9348	<0.0001	Residual		
B x S(I(G(M)))	6	15.9167	2.6528	7.0032	<0.0001	Residual	Variation at the MCA sites from before to after the declaration	MCA has caused an increase in numbers at the scale of sites
B x S(Is(G(C)))	18	10.7639	0.5980	1.5787	0.0585	Residual	No variation among control sites from before to after declaration	
T(B) x G	12	2.2396	0.1866	0.3244	0.9728	T(B) x I(G)	Eliminate	
T(Bef) x G	6							
T(Aft) x G	6							
T(B) x G(M)	4							
T(Bef) x G(M)	2	0.7443	0.3722					
T(Aft) x G(M)	2	0.0601	0.0300	0.0426	0.9584	T(B) x I(G)	No short-term temporal variation at the MCA following declaration	No short-term impact detected at scale of groups
T(B) x G(M)	8							
T(Bef) x G(C)	4	0.6481	0.1620					
T(Aft) x G(C)	4	0.7871	0.1968	0.2795	0.8869	T(B) x I(G)	No short-term temporal variation among control groups following declaration	
T(B) x I(G)	16	11.2639	0.7040	1.8585	0.0208	Residual		
T(Bef) x I(G)	8							
T(Aft) x I(G)	8							
T(B) x I(G(M))	4							
T(Bef) x I(G(M))	2	0.3889	0.1945					
T(Aft) x I(G(M))	2	7.1677	3.5834	9.4599	<0.0001	Residual	Short-term temporal variation among MCA islands following declaration	No short-term impact detected at scale of islands
T(Aft) x I(G(M)	2	7.1677	3.5834	18.4236	>0.1	T(Bef) x I(G(M))	Short-term temporal variation among MCA islands following declaration is not different from short-term variation among MCA islands prior to declaration	
T(B) x I(G(C))	12							
T(Bef) x I(G(C))	6	2.6528	0.4421					
T(Aft) x I(G(C))	6	1.0555	0.1759	0.4644	0.8349	Residual	No short-term temporal variation among control islands following declaration	
T(B) x S(I(G))	96	26.6389	0.2775	0.7326	0.973	Residual	Eliminate	
T(Bef) x S(I(G(P)))	48							
T(Aft) x S(I(G(P)))	48							
T(B) x S(I(G(M)))	24							
T(Bef) x S(I(G(M)))	12	3.1666	0.2639					
T(Aft) x S(I(G(M)))	12	8.6667	0.7222	1.9065	0.0301	Residual	Short-term variation among MCA sites following declaration	
T(Aft) x S(I(G(M)))	12	8.6667	0.7222	2.7366	>0.05	T(Aft) x S(I(G(M))) 2-tailed	Temporal variation among MCA sites after declaration is not different to temporal variation before declaration	No impact detected
T(B) x S(I(G(C)))	72							
T(Bef) x S(I(G(C)))	36	8.7778	0.2438					
T(Aft) x S(I(G(C)))	36	6.0278	0.1674	0.4419	0.9983	Residual	No short term variation among control sites following declaration	
Residual	960	363.667	0.3788					
Total	1156							

Table 3. Asymmetrical ANOVA examining abundances of Tectus pyramis between the Arnavon Islands and reference locations before and after the declaration of the MCA. B = "Before vs. After", T = Times, "MCA vs. references", G = Groups, I = Islands, S = Sites. M = MCA, R = Reference. "No test" = no appropriate MS denominator available for creating F test. "Red." = redundant term due to significant lower-order interaction. Data are Ln(X+1) transformed. Cochran's C = 0.0169, NS.

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	4.1358	4.1358			Red.		
T(B)	4	0.8971	0.2243	0.5107	0.7293	T(B) x G		
G	3	4.013	1.3377			No test		
M vs R	1	0.0133	0.0133					
G(R)	2	3.9997	1.9999					
I(G)	4	9.0441	2.2610			No test		
I(M)	1	0.6836	0.6836					
I(G(R))	3	8.3605	2.7868					
S(I(G))	24	36.2986	1.5124			Red.		
S(I(M))	6	7.4087	1.2348					
S(I(G(R))	18	28.8899	1.6050					
B x G	3	0.7919	0.2640	0.3501	0.7925	B x I(G)		
B x M vs R	1	0.6792	0.6792	0.9008	0.3963	B x I(G)	No variation at the MCA group, relative to reference groups, from before to after declaration	No effect detected at scale of groups
B x G(R)	2	0.1127	0.0564	0.0748	0.9292	B x I(G)	Pattern of variation among the reference groups was the same from before to after the declaration	
B x I(G)	4	3.0158	0.7540	No test				
B x I(M)	1	0.0362	0.0362	No test				
B x I(G(R))	3	2.9796	0.9932	No test				
B x S(I(G))	24	16.6207	0.6925	2.2202	0.0034	T(B) x S(I(G))		
B x S(I(M))	6	1.5665	0.2611	0.8371	0.5442	T(B) x S(I(G))	No change among MCA sites from before to after the declaration	Change among the control sites from before to after the declaration was co-incidental. No impact detected at scale of sites.
B x S(Is(G(R)))	18	15.0542	0.8363	2.6813	0.001	T(B) x S(I(G))	Change among reference sites from before to after the declaration	
T(B) x G	12	5.2709	0.4392	0.9202	0.5497	T(B) x I(G)		
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.7800	0.3900					
T(Aft) x M vs R	2	0.5663	0.2832	0.5933	0.5642	T(B) x I(G)	No short-term temporal variation at the MCA group, relative to reference groups, following declaration	Declaration did not affect short-term temporal trend at scale of groups
T(B) x G(R)			8					
T(Bef) x G(R)	4	0.57	0.1425					
T(Aft) x G(R)	4	3.3546	0.8387	1.7572	0.1869	T(B) x I(G)	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	7.6375	0.4773	1.5303	0.1048	T(B) x S(I(G))		
T(B) x I(M)	4							
T(Bef) x I(M))	2	0.0224	0.0112					
T(Aft) x I(M)	2	1.3009	0.6505	2.0856	0.1298	T(B) x S(I(G))	No short-term temporal variation among MCA islands following declaration	Declaration did not affect short-term temporal trend at scale of islands
T(B) x I(G(R))		12						
T(Bef) x I(G(R))	6	2.9616	0.4936					
T(Aft) x I(G(R))	6	3.3526	0.5588	1.7916	0.1089	T(B) x S(I(G))	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	29.9389	0.3119	1.2184	0.0836	Residual		
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	3.3052	0.2754					
T(Aft) x S(I(M))	12	2.5310	0.2109	0.8238	0.6259	Residual	No short-term temporal variation among MCA sites following declaration	Declaration did not affect short-term temporal trend at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	7.192	0.1998					
T(Aft) x S(I(G(R)))	36	16.9107	0.4697	1.8348	0.0022	Residual	Short-term temporal variation among reference sites following declaration	
Residual	960	245.7257	0.2560					
Total		1151						

Table 4. Asymmetrical ANOVA examining variation in abundances of clams (all species combined) between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Groups, I = Islands, S = Sites. M = MCA, R = References. "Red." = redundant term due to significant lower-order interaction. Data are Ln(X+1) transformed. Cochran's C = 0.0184, NS

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	33.4608	33.4608	61.3397	<0.001	B x S(I(G))	Variation from before to after declaration	
T(B)	4	2.778	0.6945			Red.		
G	3	24.4887	8.1629	0.8049	0.553	I(G)		
M vs R	1	10.0769	10.0769					
G(R)	2	14.4118	7.2059					
I(G)	4	40.5661	10.1415	1.635	0.198	S(I(G))		
I(M)	1	0.9941	0.9941					
I(G(R))	3	39.572	13.1907					
S(I(G))	24	148.8663	6.2028			Red.		
S(I(M))	6	35.1959	5.8660					
S(I(G(R)))	18	113.6704	6.3150					
B x G	3	0.5213	0.1738	0.1183	0.9447	B x I(G)		
B x M vs R	1	0.0001	0.0001	<0.0001	0.9982	B x I(G)	Pattern of variation at the MCA group from before to after declaration was the same as at the reference groups	No effect detected at scale of groups
B x G(R)	2	0.5212	0.2606	0.1774	0.8437	B x I(G)	Pattern of variation among reference groups was the same from before to after the declaration	
B x I(G)	4	5.8744	1.4686	2.69	0.05534	B x S(I(G))		
B x I(M)	1	0.0833	0.0833	0.153	0.699	B x S(I(G)	No change between the MCA islands from before to after the declaration	No effect detected at scale of islands. Change among reference islands was co-incidental with declaration
B x I(G(R))	3	5.7911	1.9304	23.1741	>0.20	B x S(I(G)) 2-tailed		
B x I(G(R))	3	5.7911	1.9304	3.5388	0.0298	B x S(I(G))	Change among the reference islands from before to after declaration	
B x S(I(G))	24	13.092	0.5455	1.271	0.2057	T(B) x S(I(G))		
B x S(I(M))	6	4.1775	0.6963	1.6223	0.1492	T(B) x S(I(G))	No change among the MCA sites from before to after the declaration	No effect detected at scale of sites
B x S(I(G(R)))	18	8.9145	0.4953	1.154	0.3151	T(B) x S(I(G))	No change among the reference sites from before to after the declaration	
T(B) x G	12	2.9102	0.2425	0.565	0.865	T(B) x S(I(G(P)))		
T(B) x M vs R	4	0.7653	0.1913					
T(Bef) x M vs R	2	0.5365	0.2683					
T(Aft) x M vs R	2	0.2288	0.1144	0.2665	0.7666	T(B) x S(I(G))	No short-term temporal variation at the MCA group, compared with reference groups, following declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8	2.1449	0.2681					
T(Bef) x G(R)	4	1.3139	0.3285					
T(Aft) x G(R)	4	0.831	0.2078	0.4840	0.7474	T(B) x I(G)	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	8.1168	0.5073	1.182	0.2963	T(B) x S(I(G))		
T(B) x I(M)	4							
T(Bef) x I(M)	2	0.7727	0.3864					
T(Aft) x I(M)	2	0.9275	0.4638	1.0806	0.3435	T(B) x S(I(G))	No short-term temporal variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	2.6919	0.4487					
T(Aft) x I(G(R))	6	3.7247	0.6208	1.4464	0.2051	T(B) x S(I(G))	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	41.2059	0.4292	1.3612	0.0152	Residual		
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	10.3314	0.8610					
T(Aft) x S(I(M))	12	3.4536	0.2878	0.9128	0.5333	Residual	No short-term temporal variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	13.256	0.3682					
T(Aft) x S(I(G(R)))	36	14.1649	0.3935	1.2493	0.1509	Residual	No short-term temporal variation among reference sites following declaration	
Residualidual	960	302.7282	0.3153					
Total	1156							

Table 5. Asymmetrical ANOVA examining variation in abundances of Tridacna maxima between the Arnavon Islands and Control locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Groups, I = Islands, S = Sites. M = MCA, R = References. "No test" = no appropriate MS denominator available for creating F test. "Red." = redundant term due to significant lower-order interaction. Data are Ln(X+1) transformed. Cochran's C = 0.0167, NS.

Sources of variation	DF	SS	MS	F	p	F vs	Interpretation	Implication for MCA
B	1	29.2957	29.2957			Red.		
T(B)	4	3.4566	0.8642	2.8307	0.0237	Res		
G	3	6.086	2.0287	0.2903	0.8313	I(G)		
M vs R	1	0.2515	0.2515					
G(R)	2	5.8345	2.9173					
I(G)	4	27.9499	6.9875	3.1792	0.0314	S(I(G))		
I(M)	1	0.4673	0.4673					
I(G(R))	3	27.4826	9.1609					
S(I(G))	24	52.7506	2.1979			Red		
S(I(M))	6	28.744	4.7907					
S(I(G(R)))	18	24.0066	1.3337					
B x G	3	0.1679	0.0560	0.1013	0.9551	B x I(G)		
B x M vs R	1	0.0912	0.0912	0.1649	0.7055	B x I(G)	Pattern of variation at the MCA group from before to after declaration was the same as at the reference groups	No effect detected at scale of groups
B x G(R)	2	0.0767	0.0384	0.0694	0.934	B x I(G)	Pattern of variation among reference groups was the same from before to after the declaration	
B x I(G)	4	2.212	0.5530			No test		
B x I(M)	1	0.0103	0.0103			No test		
B x I(G(R))	3	2.2017	0.7339			No test		
B x S(I(G))	24	14.0511	0.5855	1.9178	0.0228	Residual		
B x S(I(M))	6	4.3238	0.7206	1.3335	>0.5	B x S(I(G(R)) 2-tailed	Variation among MCA sites following declaration does not differ to variation among control sites	No effect detected at scale of sites
B x S(I(M)))	6	4.3238	0.7206	2.3604	0.0287	Res	Variation among MCA sites from beforeto after declaration	Change among the reference sites from before to after the
B x S(I(G(R)))	18	9.7273	0.5404	1.7701	0.0245	Res	Variation among reference sites from before to after declaration	declaration was co-incidental. No effect detected at scale of sites
T(B) x G(P)	12	2.3474	0.1956	0.5004	0.8853	T(B) x I(G)	Eliminate	
T(B) x G(M)	4							
T(Bef) x M vs R	2	0.3025	0.1513					
T(Aft) x M vs R	2	0.3475	0.1738	0.4446	0.6488	T(B) x I(G)	No short-term variation between MCA groups following declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	1.4602	0.3651					
T(Aft) x G(R)	4	0.2372	0.0593	0.1517	0.9595	T(B) x I(G)	No short-term variation among reference groups following declaration	
T(B) x I(G)	16	6.2537	0.3909	1.2804	0.202	Res		
T(B) x I(M)	4							
T(Bef) x I(M)	2	0.8849	0.4425					
T(Aft) x I(M)	2	0.6525	0.3263	1.0688	0.3438	Residual	No short-term variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	2.3089	0.3848					
T(Aft) x I(G(R))	6	2.4074	0.4012	1.3141	0.2479	Residual	No short-term variation among reference islands following declaration	
T(B) x S(I(G))	96	31.8912	0.3322	1.0881	0.2726	Residual	Eliminate	
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	7.2714	0.6060					
T(Aft) x S(I(M))	12	2.9934	0.2495	0.8172	0.6329	Residual	No short-term variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	10.4647	0.2907					
T(Aft) x S(I(G(R)))	36	11.1617	0.3100	1.0154	0.4451	Residual	No short-term variation among reference sites following declaration	
Residual	960	293.1231	0.3053					
Total	1151							

Table 6. Asymmetrical ANOVA examining variation in the abundance of holothurians found in the shallow habitat between the Arnavon Islands and reference locations before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. M = MCA, R = References. "No test" = no appropriate MS denominator available to create F test. "Red." = redundant term due to significant lower-order interaction. Data are Ln(X+1) transformed. Cochran's C = 0.0211, NS.

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	0.3971	0.3971	1.0250	0.3686	B x I(G)		
T(B)	4	0.1264	0.0316			Red		
G	3	20.8936	6.9645	1.9745	0.261	I(G)		
M vs R	1	5.485	5.4850					
G(R)	2	15.4086	7.7043					
I(G)	4	14.1088	3.5272			No test		
I(M)	1	4.6351	4.6351					
I(G(R))	3	9.4737	3.1579					
S(I(G))	4	22.2437	0.9268			Red.		
S(I(M))	6	2.9948	0.4991					
S(I(G(R))	18	19.2489	1.0694					
B x G	3	1.4899	0.4966	1.2819	0.3944	B x I(G)		
B x M vs R	1	1.445	1.4450	3.73	0.1256	B x I(G)	No variation at the MCA group, relative to reference groups, from before to after declaration	Effect detected at scale of groups
B x G(R)	2	0.0449	0.0225	0.0581	0.9443	B x I(G)	No change among control groups from before to after declaration	
B x I(G)	4	1.5496	0.3874			No test		
B x I(M)	1	0.1806	0.1806			No test		
B x I(G(R))	3	1.369	0.4563			No test		
B x S(I(G))	24	2.9343	0.1223	0.7522	0.7846	T(B) x S(I(G))	Eliminate	
B x S(I(M))	6	1.3205	0.2201	1.3536	0.2413	T(B) x S(I(G))	No change among MCA sites from before to after declaration	No effect detected at scale of sites
B x S(Is(G(R)))	18	1.6138	0.0897	0.5517	0.9246	T(B) x S(I(G))	No change among reference sites from before to after declaration	
T(B) x G	12	3.8552	0.3213	1.4037	0.2591	T(B) x I(G)	Eliminate	
T(B) x M vs R	4							
T(Bef) x M vs R	2	1.6717	0.8359					
T(Aft) x M vs R	2	1.2186	0.6093	2.6619	0.1005	T(B) x I(G)	No short-term temporal variation a the MCA group relative to the reference groups following declaration	No short-term temporalt variation at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	0.2732	0.0683					
T(Aft) x G(R)	4	0.6917	0.1729	0.7554	0.5691	T(B) x I(G)	No short-term temporal variation among control groups following declaration	
T(B) x I(G)	16	3.6624	0.2289	1.4077	0.1545	T(B) x S(I(G))		
T(B) x I(M)	4							
T(Bef) x I(M))	2	0.2938	0.1469					
T(Aft) x I(M)	2	0.3168	0.1584	0.9742	0.3812	T(B) x S(I(G))	No short-term temporal variation among reference islands following declaration.	No short-term impact detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	0.9533	0.1589					
T(Aft) x I(G(R))	6	2.0985	0.3498	2.1513	0.0544	T(B) x S(I(G))	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	15.6097	0.1626	1.2723	0.046	Residual		
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	2.1262	0.1772					
T(Aft) x S(I(M))	12	4.8536	0.4045	3.1651	0.0002	Residual	Short-term temporal variation among MCA sites following declaration	
T(Aft) x S(I(M))	12	4.8536		0.2827	>0.1	T(Bef) x S(I(G(M))) 2-tailed	Short-term temporal variation among MCA sites following declaration does not differ from variation before declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	5.543	0.1540					
T(Aft) x S(I(G(R)))	36	3.0869	0.0857	0.6708	0.9317	Residual	No short term temporal variation among reference sites following declaration	
Residual	960	122.6911	0.1278					
Total	1156							

PLATES

All photographs taken by M. Lincoln Smith, except Plate 9, lower, taken by Samson Lolo.

Plate 1. Aerial view of Sikopo Island (foreground) and Kerehikapa Island (background) within the Arnavon Islands MCA.

Plate 2. Survey of invertebrates in the shallow habitat.

Plate 3. Trochus (*Trochus niloticus*) surveyed in the shallow habitat.

Plate 4. Giant clams surveyed in the shallow habitat. Upper plate shows a *Tridacna gigas*, lower shows a *T. maxima*.

Plate 5. Survey of invertebrates in the deep habitat.

Plate 6. Diver preparing to measure a white teatfish (*Holothuria fuscogilva*) in the deep habitat.

Plate 7. Holothurians surveyed in the deep habitat. Upper plate shows elephant trunkfish (*Holothuria fuscopunctata*), lower shows prickly redfish (*Thelanota ananas*).

Plate 8. Holothurians surveyed in the deep habitat. Upper plate shows tigerfish (*Bohadschia argus*), lower shows curryfish (*Stichopus variegatus*).

Plate 9. Some of the participants in the field studies. Upper plate shows some of the crew of the *Daula*, lower shows some of the divers who undertook surveys.

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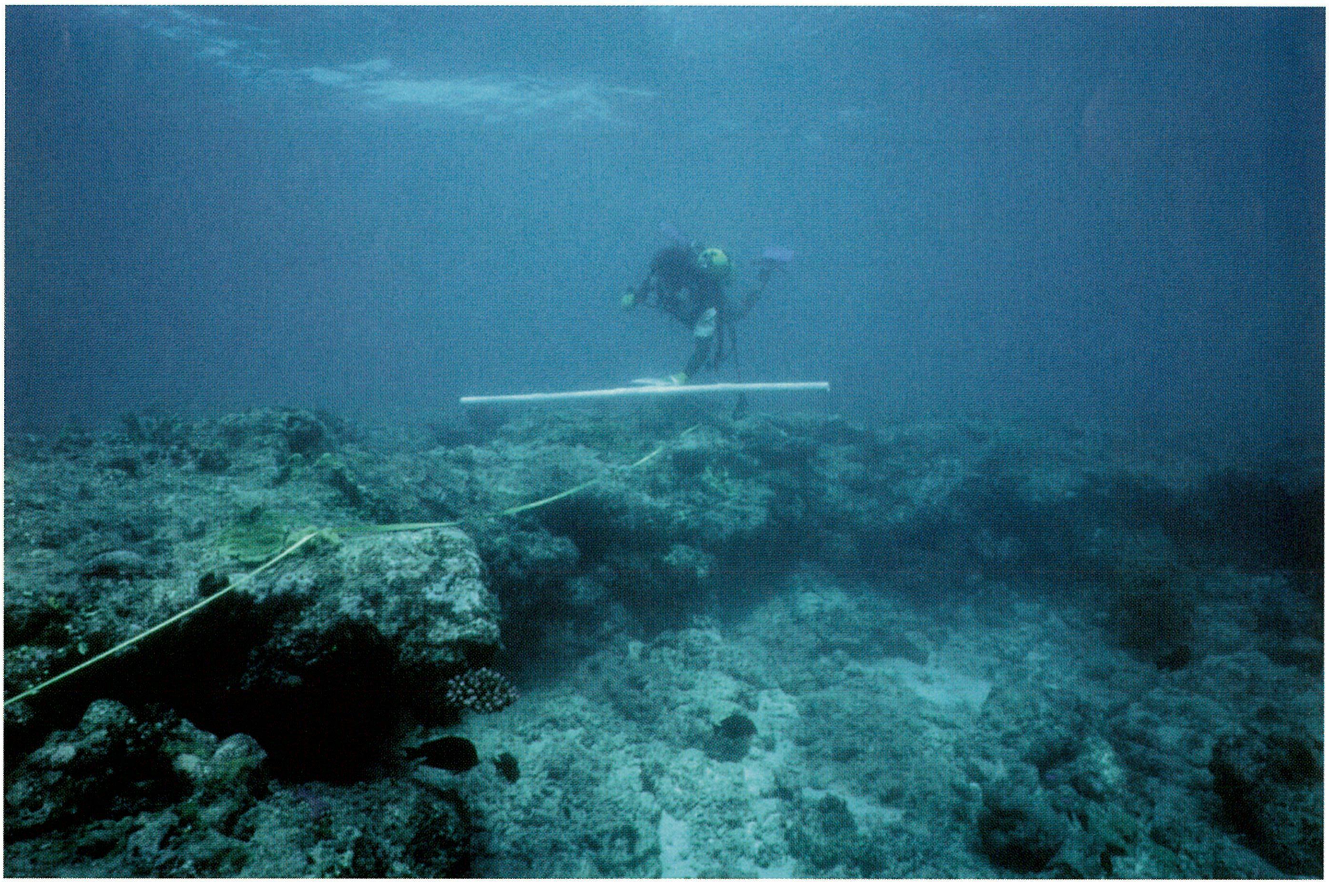
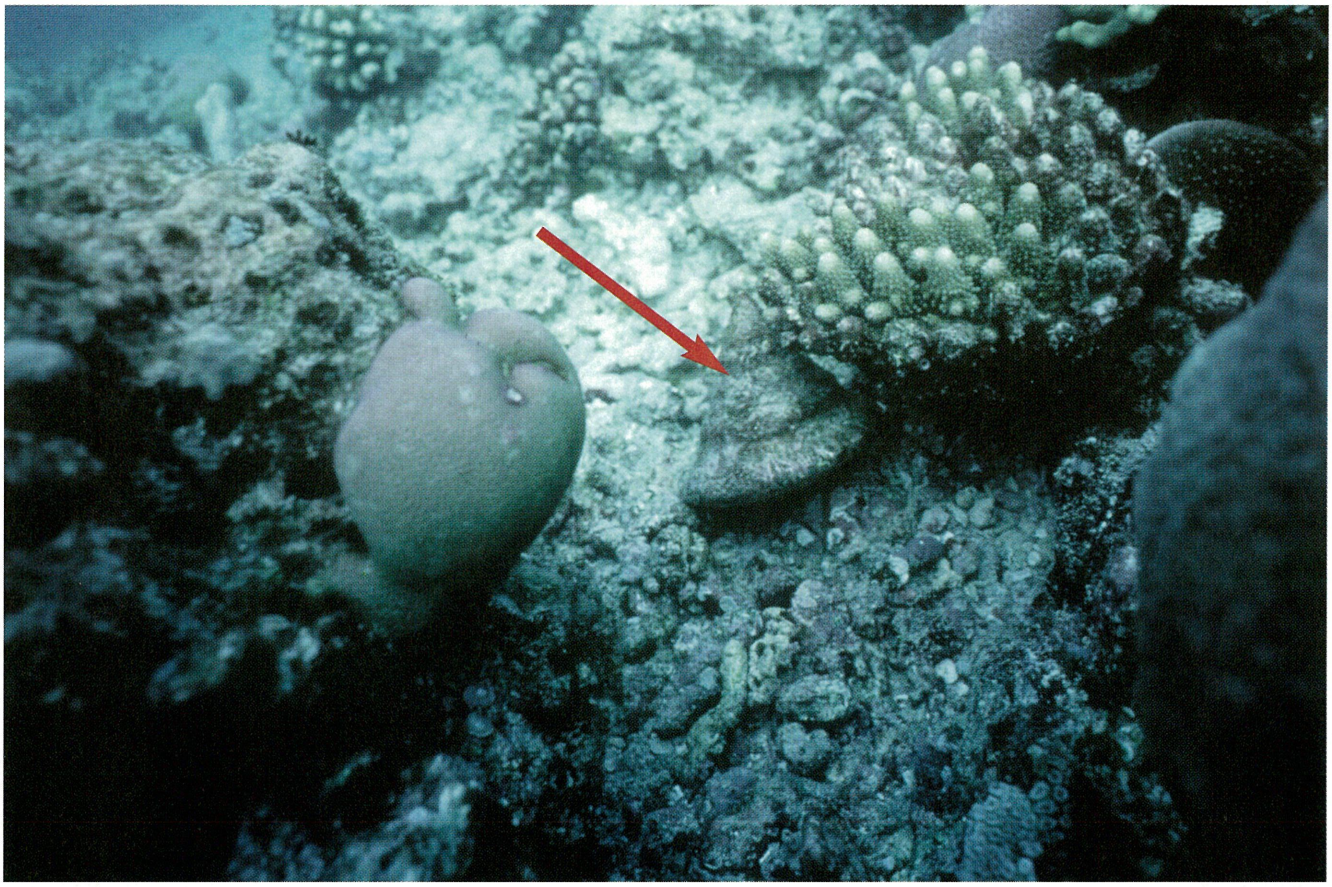


Plate 2. Survey of invertebrates in the shallow habitat.



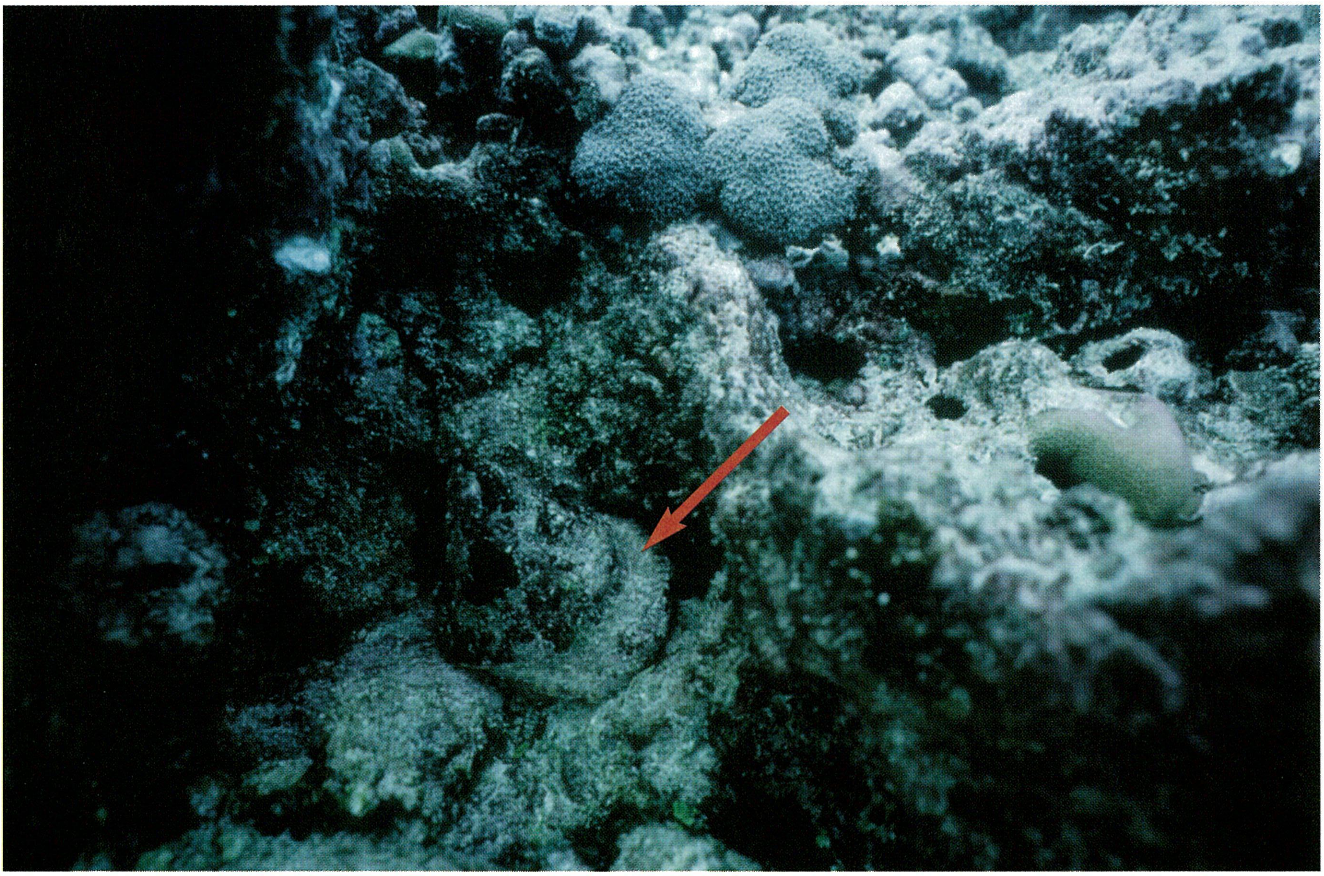
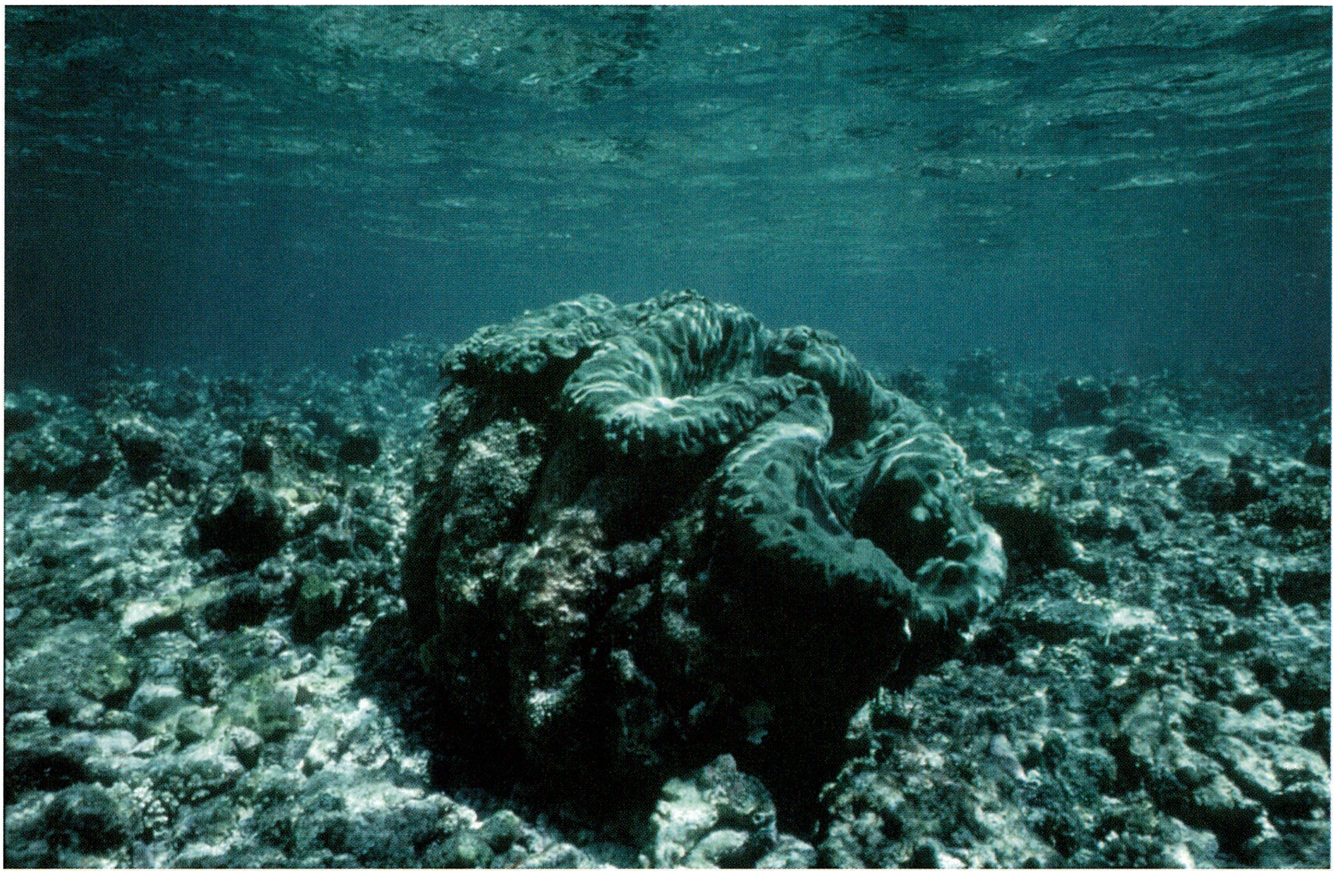


Plate 3. Trochus (*Trochus niloticus*) surveyed in the shallow habitat.



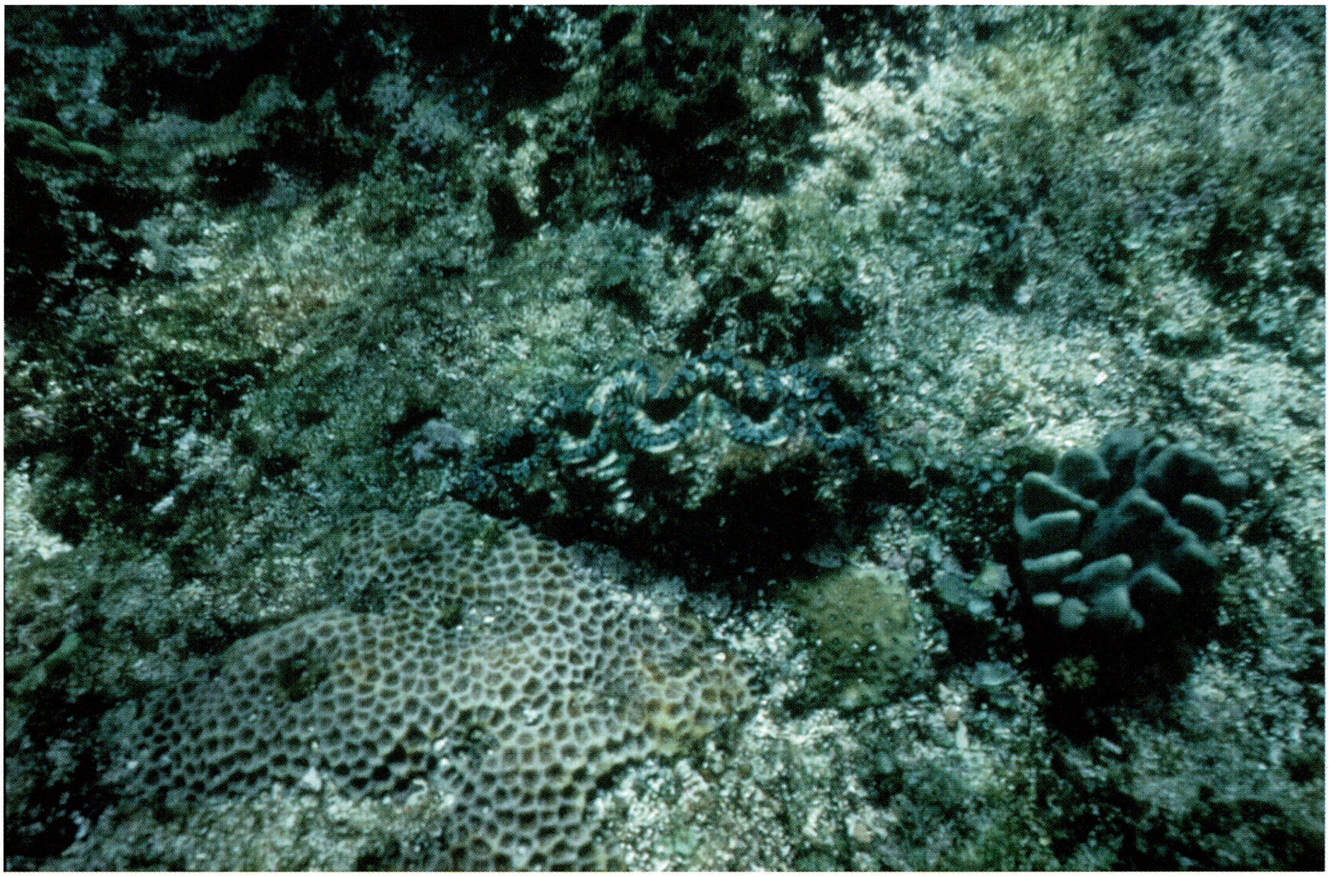


Plate 4. Giant clams surveyed in the shallow habitat. Upper plate shows a *Tridacna gigas*, lower shows a *T. maxima*.

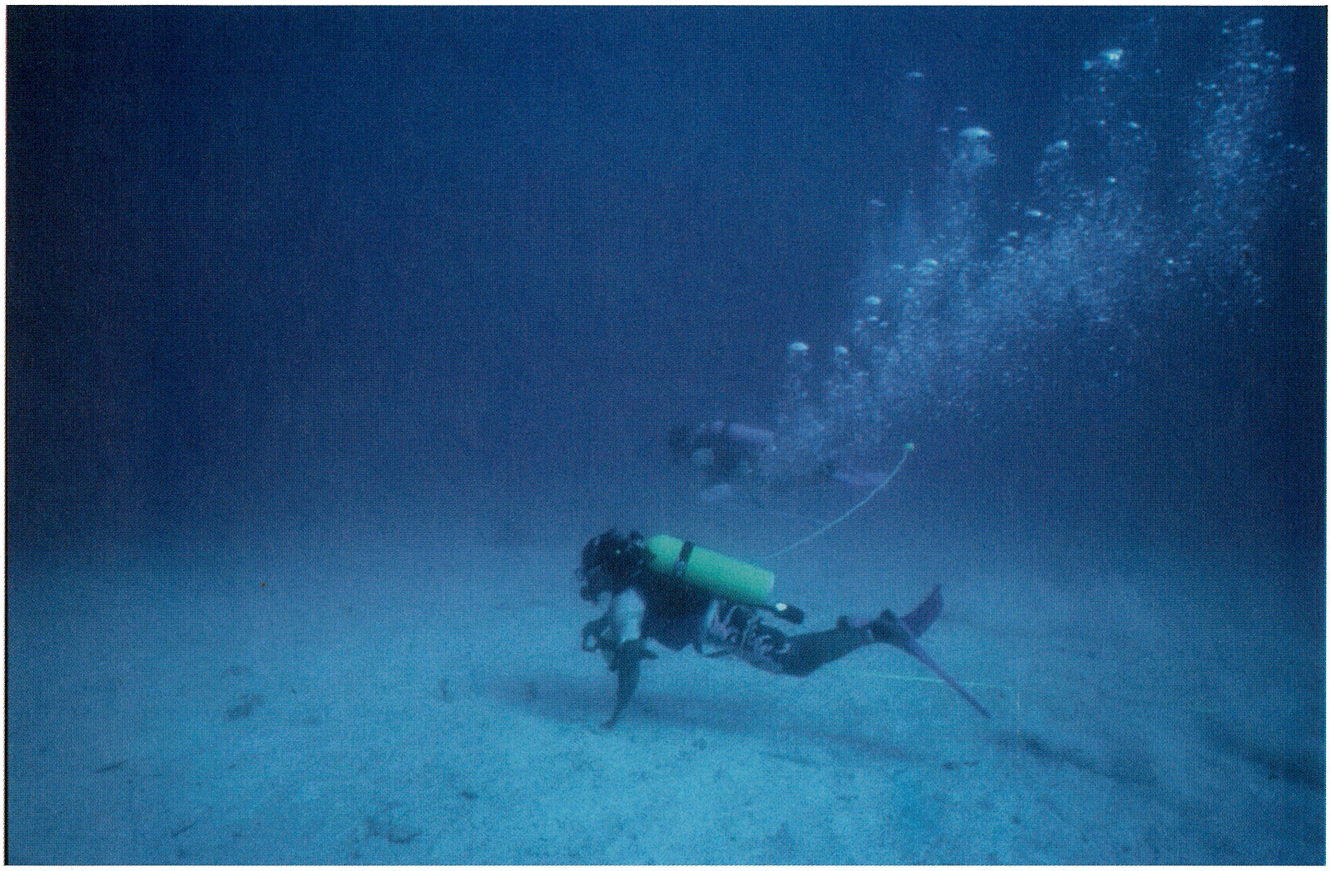


Plate 5. Survey of invertebrates in the deep habitat.

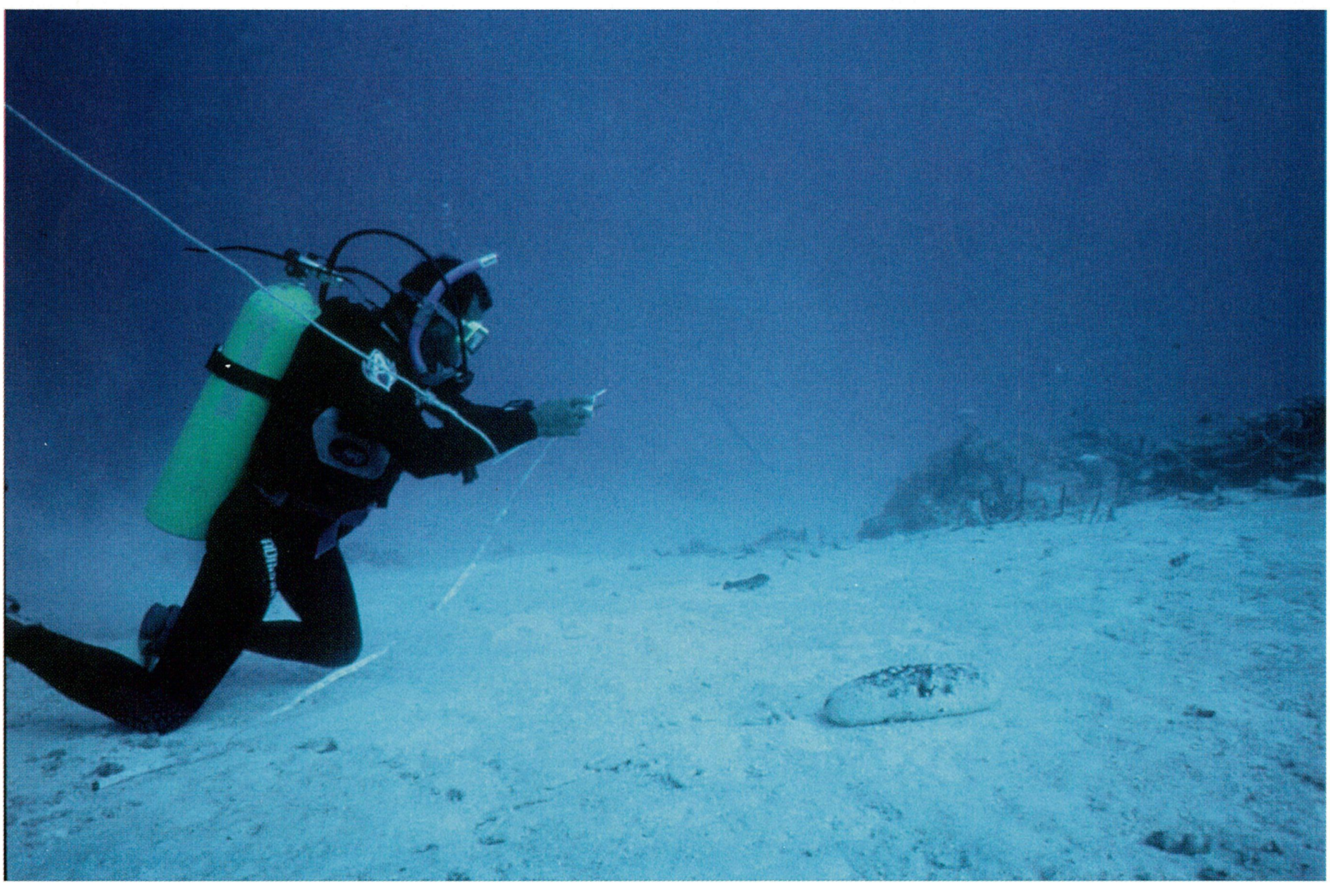
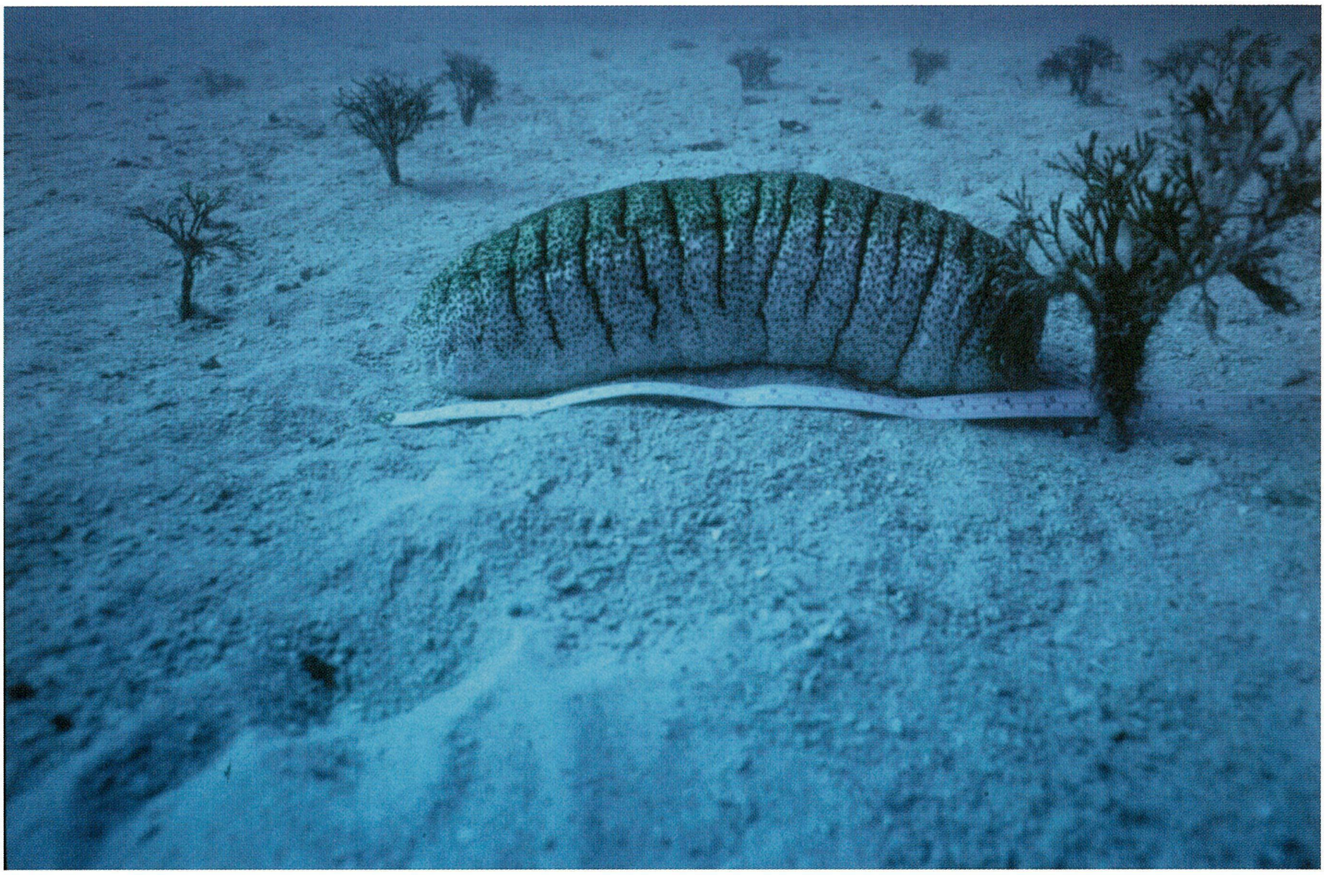


Plate 6. Diver preparing to measure a white teatfish (*Holothuria fuscogilva*) in the deep habitat.



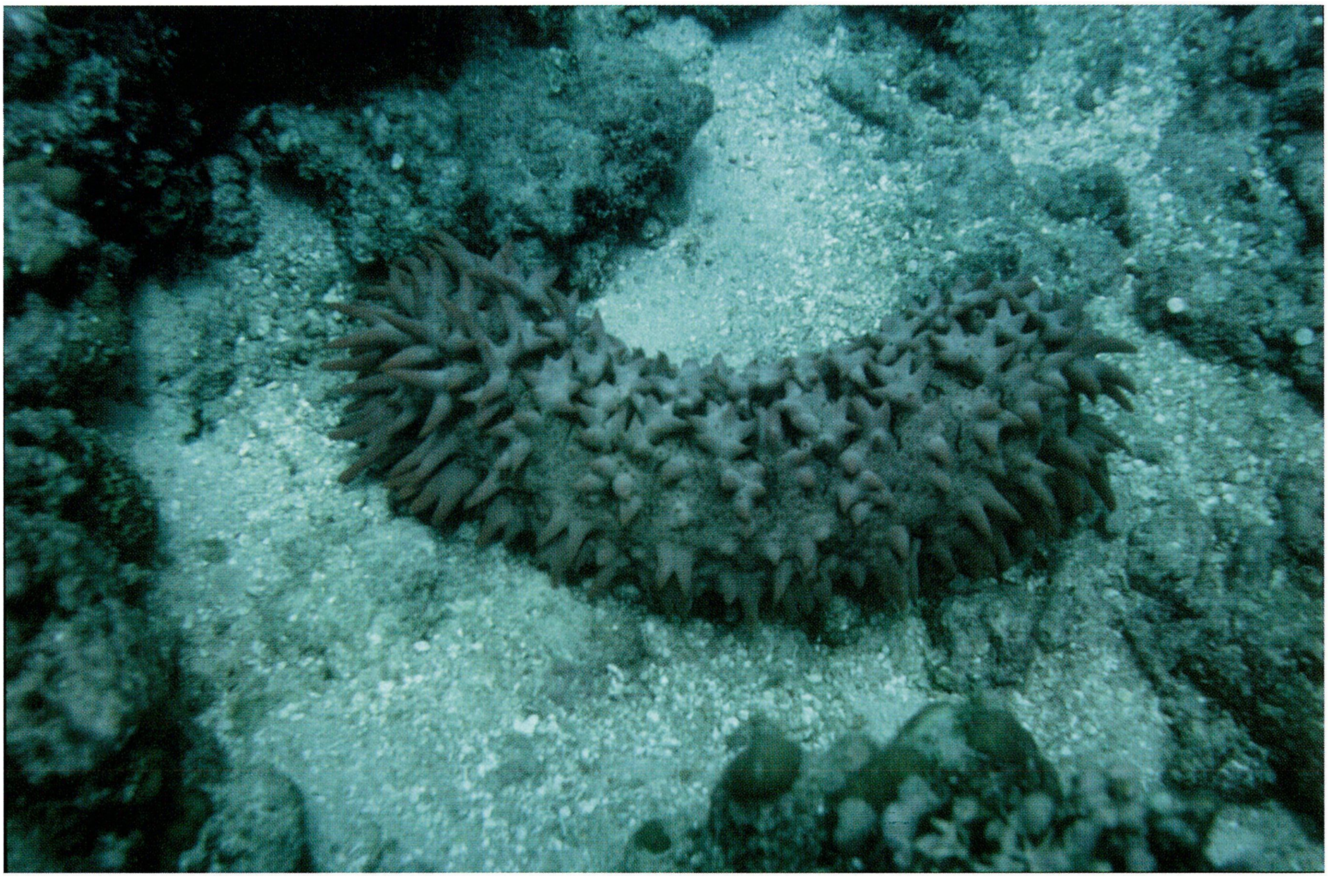
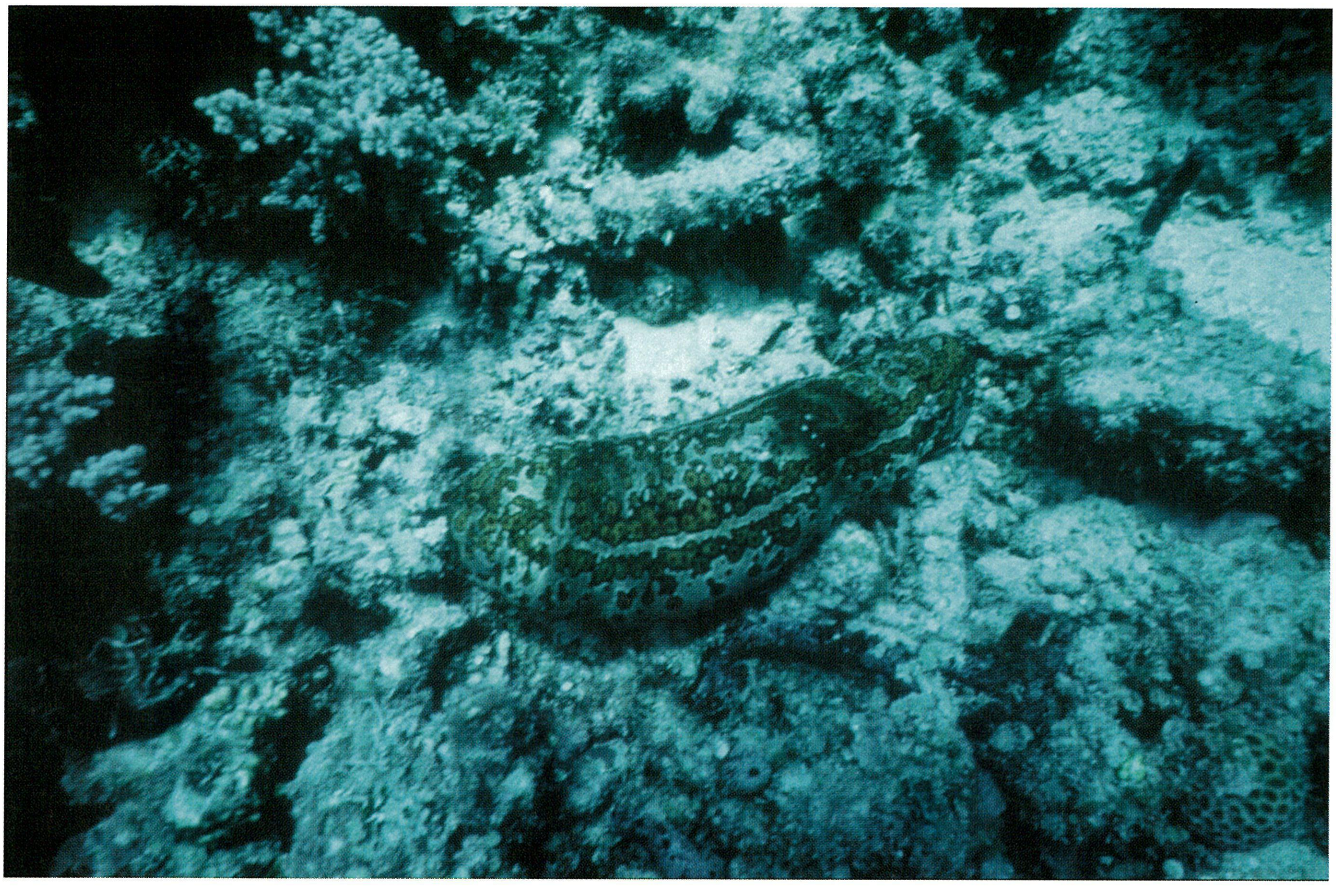


Plate 7. Holothurians surveyed in the deep habitat. Upper plate shows elephant trunkfish (*Holothuria fuscopunctata*), lower shows prickly redfish (*Thelanota ananas*).



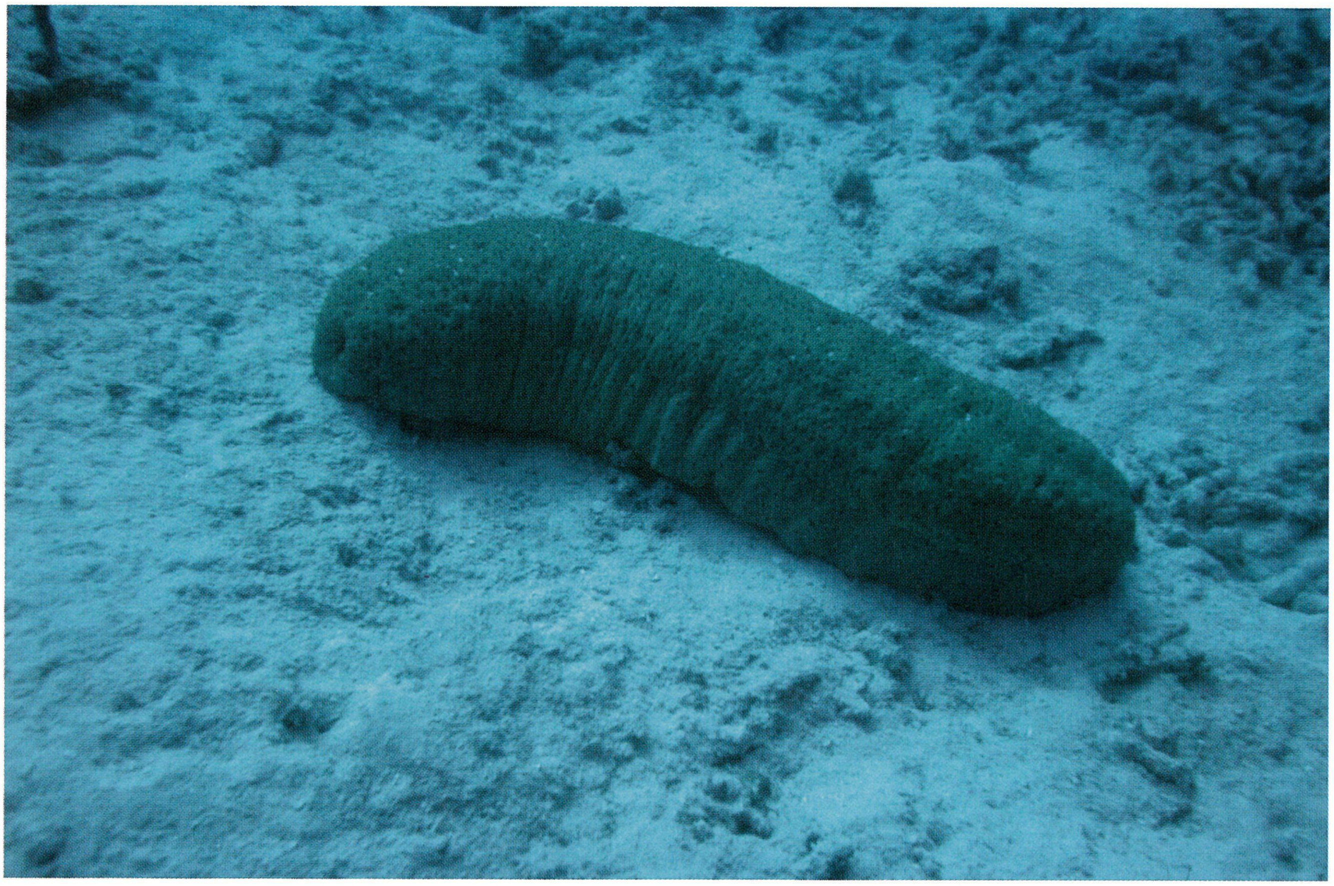


Plate 8. Holothurians surveyed in the deep habitat. Upper plate shows tigerfish (*Bohadschia argus*), lower shows curryfish (*Stichopus variegatus*).

Plate 9. Some of the participants in the field studies. Upper plate shows some of the crew of the *Daula*, lower shows some of the divers who undertook surveys.

Table 7. Asymmetrical ANOVA examining variation in the abundance of greenfish between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. M = MCA, R = References. "No test" = No appropriate MS denominator available for creating F test. Cochran's C = 0.2353, p<0.01.

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	0.0035	0.0035	0.0134	0.9134	T(B)		
T(B)	4	1.0451	0.2613	2.3583	0.0589	T(B) x S(I(G))		
G	3	6.1840	2.0613	1.0863	0.4505	I(G)		
M vs R	1	2.3437	2.3437					
G(R)	2	3.8403	1.9202					
I(G)	4	7.5903	1.8976			No test		
I(M)	1	6.7222	6.7222					
I(G(R))	3	0.8681	0.2894					
S(I(G))	24	11.4444	0.4769	3.6713	<0.0001	Res		
S(I(M))	6	6.8194	1.1366					
S(I(G(R)))	18	4.6250	0.2569					
B x G	3	0.0035	0.0012	0.0057	0.9994	T(B) x I(G)		
B x G(M)	1	0.0012	0.0012	0.0057	0.9408	T(B) x I(G)	No change at MCA group, relative to reference groups, from before to after declaration	No effect detected at scale of groups
B x G(R)	2	0.0023	0.0012	0.0057	0.9943	T(B) x I(G)	No change among reference groups from before to after declaration	
B x I(G)	4	0.1042	0.0261	0.1248	0.9714	T(B) x I(G)	Eliminate	
B x I(M)	1	0.0139	0.0139	0.0664	0.7999	T(B) x I(G)	No change at MCA islands from before to after declaration	
B x I(G(R))	3	0.0903	0.0301	0.1439	0.9321	T(B) x I(G)	No change among reference islands from before to after declaration	
B x S(I(G))	24	3.3333	0.1389	1.0693	0.3730	Residual		
B x S(I(M))	6	1.7639	0.2940	2.6534	0.0356	Residual	Variation among MCA sites from before to after declaration	MCA caused variation in abundance at scale of sites
B x S(I(G(R)))	18	1.5694	0.0872	0.6713	0.8416	Residual	No change among reference sites from before to after declaration	
T(B) x G	12	1.9687	0.1641	0.7844	0.6601	T(B) x I(G)	Eliminate	
T(B) x M	4							
T(Bef) x M	2	1.3067	0.6534					
T(Aft) x M	2	0.2824	0.1412	0.6750	0.5231	T(B) x I(G)	No short-term temporal variation within the MCA group after declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	0.0648	0.0162					
T(Aft) x G(R)	4	0.3148	0.0787	0.3762	0.8223	T(B) x I(G)	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	3.3472	0.2092	1.6105	0.0597	Residual		
T(B) x I(M)	4							
T(Bef) x I(M)	2	1.1667	0.5834					
T(Aft) x I(M)	2	0.6805	0.3403	2.6197	0.0733	Residual	No short-term temporal variation among reference islands following declaration exceeds that between MCA islands.	No short-term effect detected at scale of islands.
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	0.0972	0.0162					
T(Aft) x I(G(R))	6	1.4028	0.2338	1.7998	0.0960		No short-term temporal variation among reference islands after declaration	
T(B) x S(I(G))	96	10.6389	0.1108	0.8530	0.8378	Residual	Eliminate	
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	2.4445	0.2037					
T(Aft) x S(I(M))	12	1.9722	0.1644	1.2656	0.2335	Residual	No short-term temporal variation among MCA sites after declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	1.4722	0.0409					
T(Aft) x S(I(G(R)))	36	4.7500	0.1319	1.0154	0.4451	Residual	No short-term temporal variation among reference sites following declaration	
Residual	960	124.6667	0.1299					
Total	1151							

Table 8. Asymmetrical ANOVA examining the effect of the establishment of the MCA on the size of Tridacna maxima. B = "Before vs. After", T = Times, G = Groups. MCA = Marine Conservation Area, R = References. Cochran's C = 0.0568, p<0.05, raw data used.

Sources of variation	SS	DF	MS	F	*p*	F vs.	Interpretation	Implication
B	343.4235	1	343.4235	0.8327	0.4131	T(B)		
T(B)	1649.5891	4	412.3974	5.5973	0.0089	T(B) x G	Variation among times before and after declaration	
G	3117.6921	3	1039.2307	14.1049	0.0003	T(B) x G	Variation among groups	
BG	33.1304	3	11.0435					
B x MCA vs R	0.9941	1	0.9941	0.0105	0.9232	T(B) x M	No change in size of clams at the MCA group from before to after declaration	Establishment of MCA had no effect on the size of clams
B x R	32.1363	2	16.0682	0.2539	0.7818	T(B) x G(R)	No change in size of clams at the control groups from before to after declaration	
T(B) xG	884.1414	12	73.6785					
T(B) x MCA vs R	377.9446	4	94.4862					
T(Bef) x MCA vs R	375.0666	2	187.5333					
T(Aft) x MCA vs R	2.8780	2	1.4390	0.0314	0.969	Res	No short-term temporal variation at the MCA group following declaration	No short-term effect detected
T(B) x Among R	506.1968	8	63.2746					
T(Bef) x Among R	450.4214	4	112.6054					
T(Aft) x Among R	55.7754	4	13.9439	0.8749	0.8749	Res	No short-term temporal variation among control groups following declaration	
Residual	50526.9383	1104	0.1413					
Total	56554.9148	1127						

Table 9. Results of two-factor ANOVAs examining variation in size of Trochus niloticus between the Arnavon Islands and the reference islands and from before to after the declaration of the MCA. B = "Before vs. After", R = "Arnavons vs References". Both factors are fixed. Underlined treatments in SNK results indicate that treatments did not differ.

Cochran's C = 0.4515, p<0.01. Raw data used.

Source of variation	DF	SS	MS	F	*p*	F vs.	SNK Results				
B	1	3.6667	3.6667	1.21	0.2737	Res		MCA		References	
R	1	11.4048	11.4048	3.76	0.0547	Res		Before	After	Before	After
B x R	1	58.6667	58.3337	19.34	<0.001	Res	Mean	9.9424	11.6091	10.6879	9.6879
Res	128	388.3582	3.031				SE	0.4075	0.2158	0.2439	0.3093
Total	131	462.0964									

Table 10. Asymmetrical ANOVA examining variation in the abundance of holothurians found in the deep habitat between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. M = MCA, R = References. "Red." = redundant term due to significant lower-order interaction. Data are Ln(X+1) transformed. Cochran's C = 0.0178, NS.

Sources of variation	DF	SS	MS	F	p	F vs	Interpretation	Implication for MCA
B	1	7.4149	7.4149			Red.		
T(B)	4	1.2071	0.3018	1.2591	0.2915	T(B) x S(I(G))		
G	3	19.0224	6.3408			Red.		
M vs R	1	18.0646	18.0646					
G(R)	2	0.9578	0.4789					
I(G)	4	6.0454	1.5114	0.5894	0.6735	S(I(G))		
I(M vs R)	1	2.0773	2.0773					
I(G(R))	3	3.9681	1.3227					
S(I(G))	24	61.5463	2.5644			Red.		
S(I(M vs R))	6	33.503	5.5838					
S(I(G(R))	18	28.0433	1.5580					
B x G	3	5.7667	1.9222	3.8109	0.023	B x S(I(G))		
B x M vs R	1	4.3304	4.3304	8.5853	0.0073	B x S(I(G))	Change at the MCA group, relative to reference groups, from before to after declaration	Effect detected at scale of groups
B x G(R)	2	1.4363	0.7182	1.4238	0.2604	B x S(I(G))	No change among reference groups from before to after declaration	
B x I(G)	4	0.4849	0.1212	0.2403	0.9127	B x S(I(G))	Eliminate	
B x I(M vs R)	1	0.0368	0.0368	0.073	0.7893	B x S(I(G))	No change between MCA islands from before to after the declaration	No effect detected at scale of islands
B x I(G(R))	3	0.4481	0.1494	0.2962	0.8278	B x S(I(G))	No change among reference islands from before to after the declaration	
B x S(I(G))	24	12.1066	0.5044	1.7429	0.0150	Residual		
B x S(I(M vs R))	6	1.096	0.1827	0.6313	0.7053	Residual	No change among MCA sites from before to after the declaration	Change among the reference sites from before to after the declaration was co-incidental.
B x S(Is(G(R)))	18	11.0106	0.6117	2.1137	0.0043	Residual	Reference sites vary from before to after the declaration	
T(B) x G	12	3.5443	0.2954	1.0207	0.4270	Residual	Eliminate	
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.2202	0.1101					
T(Aft) x M vs R	2	0.9996	0.4998	1.7270	0.1784	Residual	No short-term variation at the MCA group following declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	0.5807	0.1452					
T(Aft) x G(R)	4	1.7438	0.4360	1.5066	0.1981	Residual	No short-term variation among control groups following declaration	
T(B) x I(G)	16	2.2378	0.1399	0.4834	0.9557	Residual	Eliminate	
T(B) x I(M vs R)	4							
T(Bef) x I(M vs R))	2	0.0253	0.0127					
T(Aft) x I(M vs R)	2	0.5791	0.2896	1.0007	0.3680	Residual	No short-term variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	0.3619	0.0603					
T(Aft) x I(G(R))	6	1.2715	0.2199	0.7322	0.6237	Residual	No short-term variation among reference islands following declaration	
T(B) x S(I(G))	96	23.0133	0.2397	0.8283	0.8791	Residual	Eliminate	
T(B) x S(I(M vs R))	24							
T(Bef) x S(I(M vs R))	12	3.1268	0.2606					
T(Aft) x S(I(M vs R))	12	4.1901	0.3492	1.2066	0.2732	Residual	No shor-term variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))								
T(Bef) x S(I(G(R)))	36	7.8524	0.2181					
T(Aft) x S(I(G(R)))	36	7.844	0.2179	0.7522	0.8553	Residual	No short-term variation among reference sites following declaration	
Residual	960	277.8657	0.2894					
Total	1151							

Table 11. Asymmetrical ANOVA examining variation in the abundance of white teat fish between the Arnavon Islands and control locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, P = "MCA vs. Controls", G = Group, I = Island, S = Site. M = MCA, R = References. "Red." = redundant term due to significant lower-order interaction. Cochran's C = 0.2308, p<0.01.

Sources of variation	DF	SS	MS	F	*p*	F vs	Interpretation	Implication for MCA
B	1	2.0842	2.0842			Red.		
T(B)	4	0.9132	0.2283	1.0574	0.3819	T(B) x S(I(G))		
G	3	9.3845	3.1282			Red.		
M vs R	1	5.1183	5.1183					
G(R)	2	4.2662	2.1331					
I(G)	4	10.0382	2.5096	1.3826	0.2697	S(I(G))		
I(M)	1	4.7535	4.7535					
I(G(R))	3	5.2847	1.7616					
S(I(G))	24	43.5625	1.8151			Red.		
S(I(M)	6	19.4653	3.2442					
S(I(G(R)))	18	24.0972	1.3387					
B x G	3	7.1345	2.3782	2.044	0.1300	B x I(G)		
B x M vs R	1	7.1322	7.1322	6.13	0.0207	B x I(G)	Variation at the MCA group, relative to reference groups, from before to after the declaration	MCA had an effect at scale of groups
B x G(R)	2	0.0023	0.0012	0.001	0.9990	B x S(I(G))	No variation among reference groups from before to after the declaration	
B x I(G)	4	4.0521	1.0130	0.8706	0.5028	B x S(I(G))	Eliminate	
B x I(M)	1	0.0868	0.0868	0.0746	0.7871	B x S(I(G))	No variation between the MCA islands from before to after the declaration	No effect detected at scale of islands
B x I(G(R))	3	3.9653	1.3218	1.1049	0.3665	B x S(I(G))	No variation among reference islands from before to after the declaration	
B x S(I(G))	24	27.9236	1.1635	2.7185	<0.0001	Residual		
B x S(I(M))	6	9.4563	1.5776	3.686	0.0013	Residual	Variation among MCA sites from before to after the declaration	No effect detected at scale of sites. Change among reference sites was co-incidental with declaration
B x S(I(M))	6	9.4563	1.5776	1.5384	>0.5	B x S(I(G(R))) 2-tailed	Variation among MCA sites from before to after the declaration did not differ from variation among reference sites	
B x S(I(G(R)))	18	18.4583	1.0255	2.396	0.0009	Residual	Variation among the reference sites from before to after the declaration	
T(B) x G	12	3.6007	0.3001	0.7012	0.7514	Residual	Eliminate	
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.6667	0.3334					
T(Aft) x M vs R	2	1.1470	0.5735	1.34	0.2623	Residual	No short-term temporal variation at the MCA group, relative to reference groups, following declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	1.4444	0.3611					
T(Aft) x G(R)	4	0.3426	0.0857	0.2002	0.9383	Residual	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	4.4306	0.2769	0.647	0.8466	Residual		
T(B) x I(M)	4							
T(Bef) x I(M)	2	1.0555	0.5278					
T(Aft) x I(M)	2	2.0001	1.0001	2.3367	0.0972	Residual	No short-term temporal variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	1.2778	0.2130					
T(Bef) x I(G(R))	6	0.0972	0.0162	0.0379	0.9998	Residual	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	20.7222	0.2159	0.504439	>0.9999	Residual	Eliminate	
T(B) x S(I(M))	24	11.9444	0.4977	1.1628	0.2676	Residual	Eliminate	
T(Bef) x S(I(M))	12	2.1111	0.1759					
T(Aft) x S(I(M))	12	9.8333	0.8194	1.9145	0.0293	Residual	Short-term temporal variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(Aft) x S(I(M))	12	9.8333	0.8194	4.6583	<0.02	T(Bef) x S(I(G(M) 2 tailed sites	Temporal variation among MCA before declaration differs from after declaration	
T(Bef) x S(I(G(R)))	36	6.6667	0.1852	3.16041	<0.005	T(Aft) x S(I(G(R) 2 tailed	Temporal variation among reference sites before declaration differs from after declaration	
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	6.6667	0.1852					
T(Aft) x S(I(G(R)))	36	2.1110	0.0586	0.1369	>0.9999	Residual	No short-term temporal variation among reference sites following declaration	
Residual	960	410.8333	0.4280					
Total	1151							

Table 12. Asymmetrical ANOVA examining variation in the abundance of lollyfish between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. M = MCA, R = References. Cochran's C = 0.1536, p<0.01.

Sources of variation	DF	SS	MS	F	p	F vs	Interpretation	Implication for MCA
B	1	1.5313	1.5313	1.96648	0.23346	T(B)		
T(B)	4	3.1146	0.7787	1.42021	0.22519	Residual		
G	3	78.7708	26.2569	2.29535	0.10338	S(I(G))		
M vs R	1	75.8518	75.8518					
G(R)	2	2.9190	1.4595					
I(G)	4	40.0625	10.0156	0.87555	0.49308	S(I(G))		
I(M)	1	28.7535	28.7535					
I(G(R))	3	11.3090	3.7697					
S(I(G))	24	274.5417	11.4392	20.863	<0.0001	Residual	Variation among sites within groups	
S(I(M))	6	254.1042	42.3507					
S(I(G(R)))	18	20.4375	1.1354					
B x G	3	0.9063	0.3021	0.551	0.6476	Residual		
B x M vs R	1	0.5105	0.5105	0.9311	0.3348	Residual	No change at MCA from before to after declaration	No effect detected at scale of groups
B x G(R)	2	0.3958	0.1979	0.3609	0.8383	Residual	No change among reference groups from before to after declaration	
B x I(G)	4	2.2431	0.5608	1.0228	0.3944	Residual		
B x I(M)	1	1.0035	1.0035	1.8302	0.1764	Residual	No change between the MCA islands from before to after the declaration	No effect detected at scale of islands
B x I(G(R))	3	1.2396	0.4132	0.7536	0.5204	Residual	No change among the reference islands from before to after the declaration	
B x S(I(G))	24	4.2750	0.1781	0.3248	0.9992	Residual	Eliminate	
B x S(I(M))	6	1.3931	0.2322	0.4235	0.8636	Residual	No change among the MCA sites from before to after the declaration	No effect detected at scale of sites
B x S(I(G(R)))	18	2.8819	0.1601	0.292	0.9983	Residual	No change among the reference sites from before to after the declaration	
T(B) x G	12	7.4688	0.6224	1.1351	0.3273	Residual	Eliminate	
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.1956	0.0978					
T(Aft) x M vs R	2	5.6713	2.8357	5.1718	0.0058	Residual	Short-term temporal variation at the MCA group following declaration	No short-term effect detected at scale of groups. Change at the MCA group was not co-incident with declaration of MCA
T(Aft) x M vs R	2	5.6713	2.8357	28.9949	>0.05	T(Bef) x M vs R	Short-term temporal variation at the MCA group following declaration differs to temporal variation before declaration	
T(B) x G(R)	8						Eliminate	
T(Bef) x G(R)	4	1.4398	0.3600					
T(Bef) x G(R)	4	1.4398	0.3600	8.8889	>0.05	T(Aft) x G(R)	No difference among reference groups from before to after declaration	
T(Aft) x G(R)	4	0.1621	0.0405	0.0739	0.9901	Residual	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	4.9444	0.3090	0.5636	0.9117	Residual	Eliminate	
T(B) x I(M)	4							
T(Bef) x I(M)	2	0.5416	0.2708					
T(Aft) x I(M)	2	1.7222	0.8611	1.5705	0.2085	Residual	No short-term temporal variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	2.4167	0.4028					
T(Aft) x I(G(R))	6	0.2639	0.0440	0.0803	0.9228	Residual	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	36.5833	0.3811	0.6951	0.9876	Residual	Eliminate	
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	3.3334	0.2778					
T(Aft) x S(I(M))	12	19.2777	1.6065	2.93	0.0005	Residual	Short-term temporal variation among MCA sites following declaration	No short-term effect detected at scale of sites. Temporal variation from before to after declaration occurred for both the MCA and reference sites.
T(Aft) x S(I(M))	12	19.2777	1.6065	5.7829	<0.005	T(Bef) x S(I(M))	Short-term temporal variation among MCA sites following declaration is no different to the short-term temporal variation among MCA sites prior to declaration	
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	11.0833	0.3079	3.8392	<0.01	T(Aft) x S(I(G(R)))	Short-term temporal variation among reference sites differs from before to after declaration.	
T(Aft) x S(I(G(R)))	36	2.8889	0.0802	0.1463	>0.9999	Residual	No short-term temporal variation among reference sites following declaration	
Residual	960	526.3333	0.5483					
Total	1151							

Table 13. Asymmetrical ANOVA examining variation in the abundance of amberfish between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, G = Group, I = Island, S = Site. M = MCA, R = References. "Red." = redundant term due to significant lower-order interaction. Cochran's C = 0.0937, p<0.01.

Sources of variation	DF	SS	MS	F	*p*	F vs.	Interpretation	Implication for MCA
B	1	4.8828	4.8828			Red.		
T(B)	4	2.8646	0.7162	1.9310	0.1115	T(B) x S(I(G))		
G	3	25.0443	8.3481	0.8927	0.5179	I(G)		
M vs R	1	5.2735	5.2735					
G(R)	2	19.7708	9.8854					
I(G)	4	37.4063	9.3516	4.2164	0.0100	S(I(G))		
I(M)	1	0.5000	0.5000					
I(G(R))	3	36.9063	12.3021					
S(I(G))	24	53.2292	2.2179			Red.		
S(I(M))	6	6.4445	1.0741					
S(I(G(R)))	18	46.7847	2.5992					
B x G 3	7.3012		2.4337	0.9546	0.4949	B x I(G)		
B x M vs R	1	3.8267	3.8267	1.5010	0.2877	B x I(G)	Change at the MCA group, relative to reference groups, from before to after the declaration	Effect detected at scale of groups
B x G(R) 2	3.4745		1.7373	0.6814	0.5563	B x I(G)	No change among control groups from before to after the declaration	
B x I(G)	4	10.1979	2.5495	2.5667	0.0640	B x S(I(G))		
B x I(M)	1	0.0139	0.0139	0.0140	0.9068	B x S(I(G))	No change between MCA islands from before to after the declaration	No effect detected at scale of islands.
B x I(G(R))	3	10.1840	3.3947	3.4176	0.0335	B x S(I(G))	No change among the reference islands from before to after the declaration	
B x S(I(G))	24	23.8381	0.9933	2.6781	0.0004	T(B) x S(I(G))		
B x S(I(M))	6	2.1645	0.3608	0.9728	0.4424	T(B) x S(I(G))	No change among MCA sites	No effect detected at
scale								
							from before to after the declaration	of sites. Change among reference sites was co-incidental with declaration.
B x S(I(G(R)))	18	21.6736	1.2041	3.2464	<0.0001	T(B) x S(I(G))	Change among the reference sites from before to after the declaration	
T(B) x G 12	5.0660		0.4222	1.1383	0.3392	T(B) x S(I(G))	Eliminate	
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.3102	0.1551					
T(Aft) x M vs R	2	0.1123	0.0561	0.1513	0.8598	T(B) x S(I(G))	No short-term temporal variation at the MCA group following declaration	No short-term effect detected at scale of groups
T(Bef) x G(R)	4	2.3565	0.5891					
T(Aft) x G(R)	4	2.2870	0.5718	1.5417	0.1963	T(B) x S(I(G))	No short-term temporal variation among reference groups following declaration	
T(B) x I(G)	16	4.1250	0.2578	0.6951	0.7924	T(B) x S(I(G))	Eliminate	
T(B) x I(M)	4							
T(Bef) x I(M)	2	0.3889	0.1945					
T(Aft) x I(M)	2	0.2639	0.1320	0.3559	0.7015	T(B) x S(I(G))	No short-term temporal variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	2.2361	0.3727					
T(Aft) x I(G(R))	6	1.2361	0.2060	0.5554	0.7647	T(B) x S(I(G))	No short-term temporal variation among reference islands following declaration	
T(B) x S(I(G))	96	35.6111	0.3709	1.1565	0.1538	Residual		
T(B) x S(I(M))	24							
T(Bef) x S(I(M))	12	1.6667	0.1389					
T(Aft) x S(I(M))	12	3.7777	0.3148	0.9816	0.4645	Residual	No short-term temporal variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72	30.1667	0.4190	1.3065	0.0489	Residual		
T(Bef) x S(I(G(R)))	36	19.4444	0.5401					
T(Aft) x S(I(G(R)))	36	10.7223	0.2978	0.9286	0.5910	Residual	No short-term temporal variation among reference sites following declaration	
Residual960	307.8333		0.3207					
Total	1151							

Table 14. Asymmetrical ANOVA examining variation in the abundance of elephant trunk fish between the Arnavon Islands and reference locations, before and after the declaration of the MCA. B = "Before vs. After", T = Times, I = Island, S = Site. M = MCA, R = References. "Red." = redundant term due to significant lower-order interaction. Cochran's C = 0.0975, p<0.01.

Sources of variation	DF	SS	MS	F	*p*	F vs.	Interpretation	Implication for MCA
B	1	0.0139	0.0139			Red.		
T(B)	4	0.4306	0.1077	0.3416	0.8499	Residual		
G	3	6.434	2.1447	0.3316	0.8043	I(G)		
M vs R	1	1.9456	1.9456					
G(R)	2	4.4884	2.2442					
I(G)	4	25.8681	6.4670	1.9765	0.1304	S(I(G))		
I(M vs R)	1	2.1702	2.1702					
I(G(R))	3	23.6979	7.8993					
S(I(G))	24	78.5278	3.2720			Red.		
S(I(M vs R))	6	6.3542	1.0590					
S(I(G(R))	18	72.1736	4.0096					
B x G 3	1.7986	0.5995	0.6177	0.6392	B xI(G)			
B x M vs R	1	0.463	0.4630	0.4771	0.5277	B xI(G)	No variation at the MCA group, relative to reference groups, from before to after declaration	No effect detected at scale of groups
B x G(R)	2	1.3356	0.6678	0.6881	0.5536	B xI(G)	No variation among control groups from before to after declaration	
B x I(G) 4	3.8819	0.9705	1.5791	0.2121	B x S(I(G))			
B x I(M vs R)	1	0.7812	0.7812	1.2711	0.2707	B x S(I(G))	No variation between MCA islands from befor to after declaration	No effect detected at scale of islandse
B x I(G(R))	3	3.1007	1.0336	1.6817	0.1975	B x S(I(G))	No variation among reference islands from before to after declaration	
B x S(I(G))	24	14.75	0.6146	1.9493	0.0042	Residual		
B x S(I(M vs R))	6	4.1042	0.6840	2.1694	0.0437	Residual	Variation among MCA sites from before to after declaration	No effect detected at scale of sites. Similar variation at both MCA and reference sites
B x S(I(G(R)))	18	10.6458	0.5914	1.8756	0.0147	Residual	Variation among reference sites from before to after declaration	
T(B) x G 12	3.6528	0.3044	0.9654	0.4804	Residual	Eliminate		
T(B) x M vs R	4							
T(Bef) x M vs R	2	0.6077	0.3039					
T(Aft) x M vs R	2	0.1747	0.0873	0.2769	0.7582	Residual	No short-term variation at the MCA group, relative to reference groups, following declaration	No short-term effect detected at scale of groups
T(B) x G(R)	8							
T(Bef) x G(R)	4	1.3611	0.3403					
T(Aft) x G(R)	4	1.5093	0.3773	1.1966	0.3107	Residual	No short-term variation among reference groups following declaration	
T(B) x I(G)	16	3.3333	0.2083	0.6606	0.8342	Residual	Eliminate	
T(B) x I(M vs R)	4							
T(Bef) x I(M vs R))	2	0.4306	0.2153					
T(Aft) x I(M vs R)	2	0.4305	0.2153	0.6828	0.5054	Residual	No short-term variation between MCA islands following declaration	No short-term effect detected at scale of islands
T(B) x I(G(R))	12							
T(Bef) x I(G(R))	6	1.0694	0.1782					
T(Aft) x I(G(R))	6	1.4028	0.2338	0.7574	0.6036	Residual	No short-term variation among reference islands following declaration	
T(B) x S(I(G))	96	25.8056	0.2688	0.8525	0.8387	Residual	Eliminate	
T(B) x S(I(M vs R))	24							
T(Bef) x S(I(M vs R))	12	2.4444	0.2037					
T(Aft) x S(I(M vs R))	12	1.5556	0.1296	0.4110	0.9598	Residual	No short-term variation among MCA sites following declaration	No short-term effect detected at scale of sites
T(B) x S(I(G(R)))	72							
T(Bef) x S(I(G(R)))	36	15.1389	0.4205					
T(Aft) x S(I(G(R)))	36	6.6667	0.1852	0.5874	0.9755	Residual	No short-term variation among reference sites following declaration	
Residual960	302.6667 0.3153							
Total	1151							

Table 15. Results of two-factor ANOVAs examining variation in size of invertebrate species in the deep habitat, between the MCA and the reference areas and from before to after the declaration of the MCA. B = "Before vs. After", M = "MCA vs References". Underlined treatments in SNK results indicate that treatments did not differ. Raw data used for all analyses.

Species	Cochran's C	Source of variation	DF	SS	MS	F	*p*	F vs.	SNK Results				
Lollyfish	0.3171, NS	B	1	109.8218	109.822	3.1	0.0797	Res					
n=69		M	1	274.6018	274.602	7.74	0.0058	Res					
		B x M	1	101.896	101.896	2.87	0.0913	Res					
		Res	272	9651.1675	35.4822								
Elephant's trunk fish	0.3261, NS	B	1	28.3081	28.3081	1.07	0.3026	Res					
n=40		M	1	124.7856	124.786	4.72	0.0314	Res					
		B x M	1	0.0856	0.0856	0.003	0.9547	Res					
		Res	156	4128.2378	26.4631								
White teat fish	0.3108, NS	B	1	5.6	5.6	0.14	0.7055	Res		MCA		References	
n=35		M	1	55.3143	55.3143	1.42	0.2361	Res		Before	After	Before	After
		B x M	1	192.1143	192.114	4.92	0.0282	Res	Mean	41.9571	40.0143	40.8714	43.6143
		Res	136	5312.1429	39.0599				SE	1.1534	1.0571	1.1779	0.7928

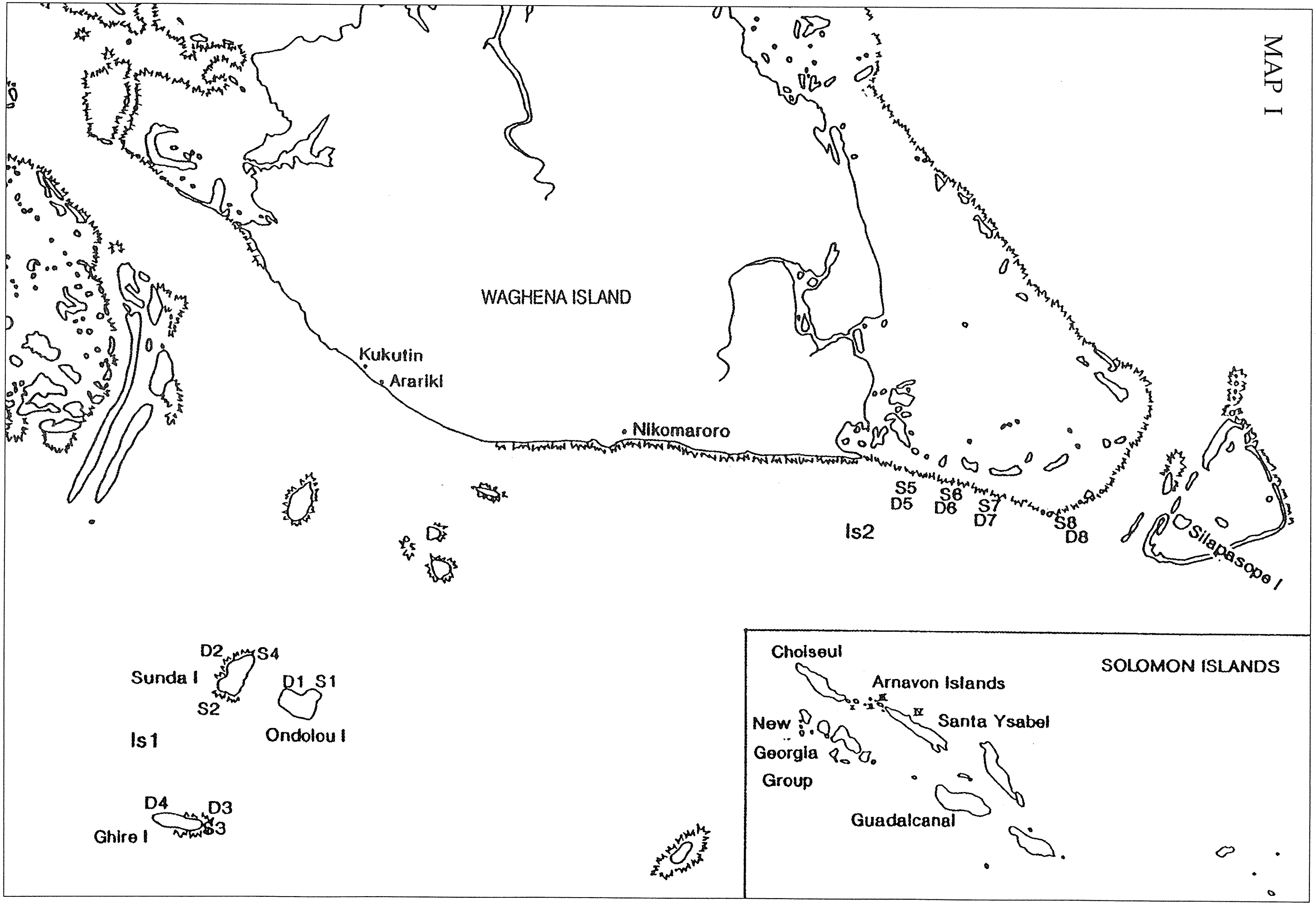
Table 16. Comparison of densities of selected exploited invertebrates at the Arnavon Islands after the declaration of the MCA and at other locations in the Indo-Pacific. nd = no data. Adapted from Lincoln Smith *et al.* (1997).

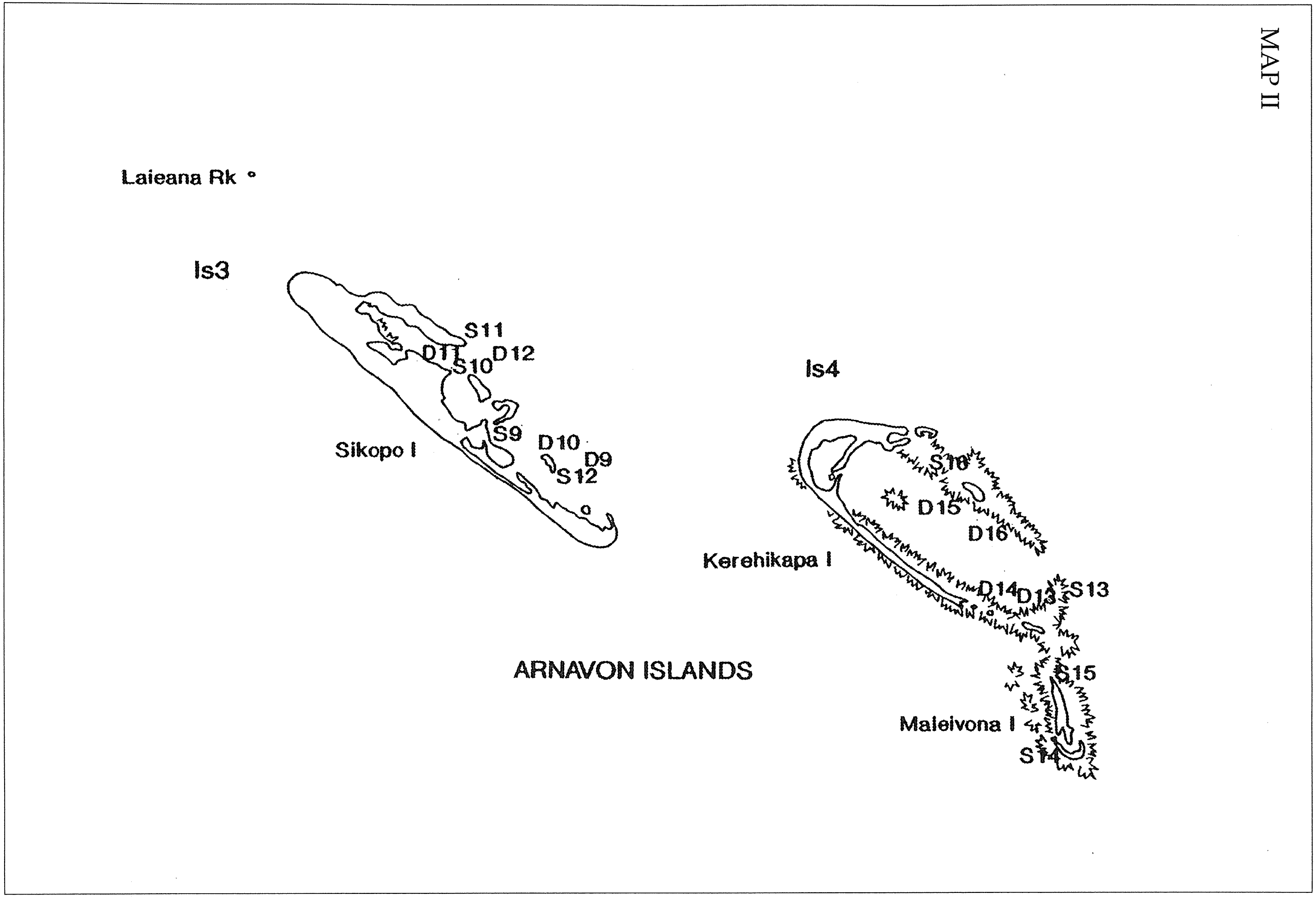
Species	Mean density (no. ha^{-1})	Mean density (no. ha^{-1})	Max. density (no. ha^{-1})	Source
Trochus niloticus	57	222-2016	2275	Nash *et al.* (1995)
		nd	1290	Tsutsui and Sigrah (1994)
		62-590	nd	Long et al. (1993)
Tridacna maxima	25	nd	>1000	Munro (1993)
Stichopus chloronotus	16	nd	4258	Preston (1993)
Holothuria atra	26.8	545	720	Preston (1993)
Holothuria fuscopunctata	12.8	22	106	Preston (1993)
Holothuria fuscogilva	16	11-18.4	81.7	Preston (1993)
Thelanota anax	6.4	41	241	Preston (1993)

FIGURES

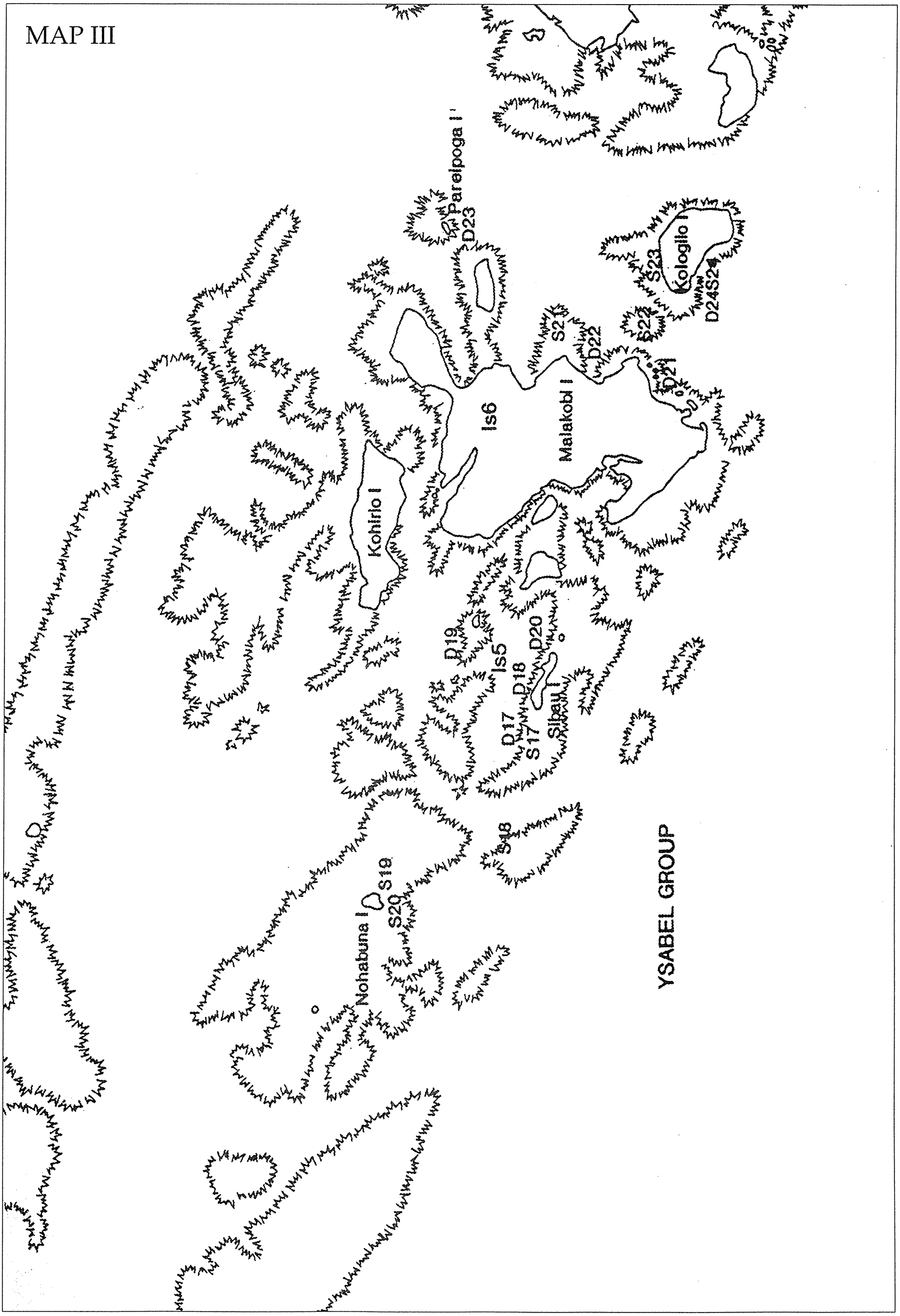
Figure 1. The study area and sampling sites on the following pages.

- Map I Waghena Group and inset of Solomon Islands, showing approximate position of Groups (I-IV) within the study region.
- Map II Arnavon Islands Group.
- Map III Ysabel Group.
- Map IV Suavanao Group.

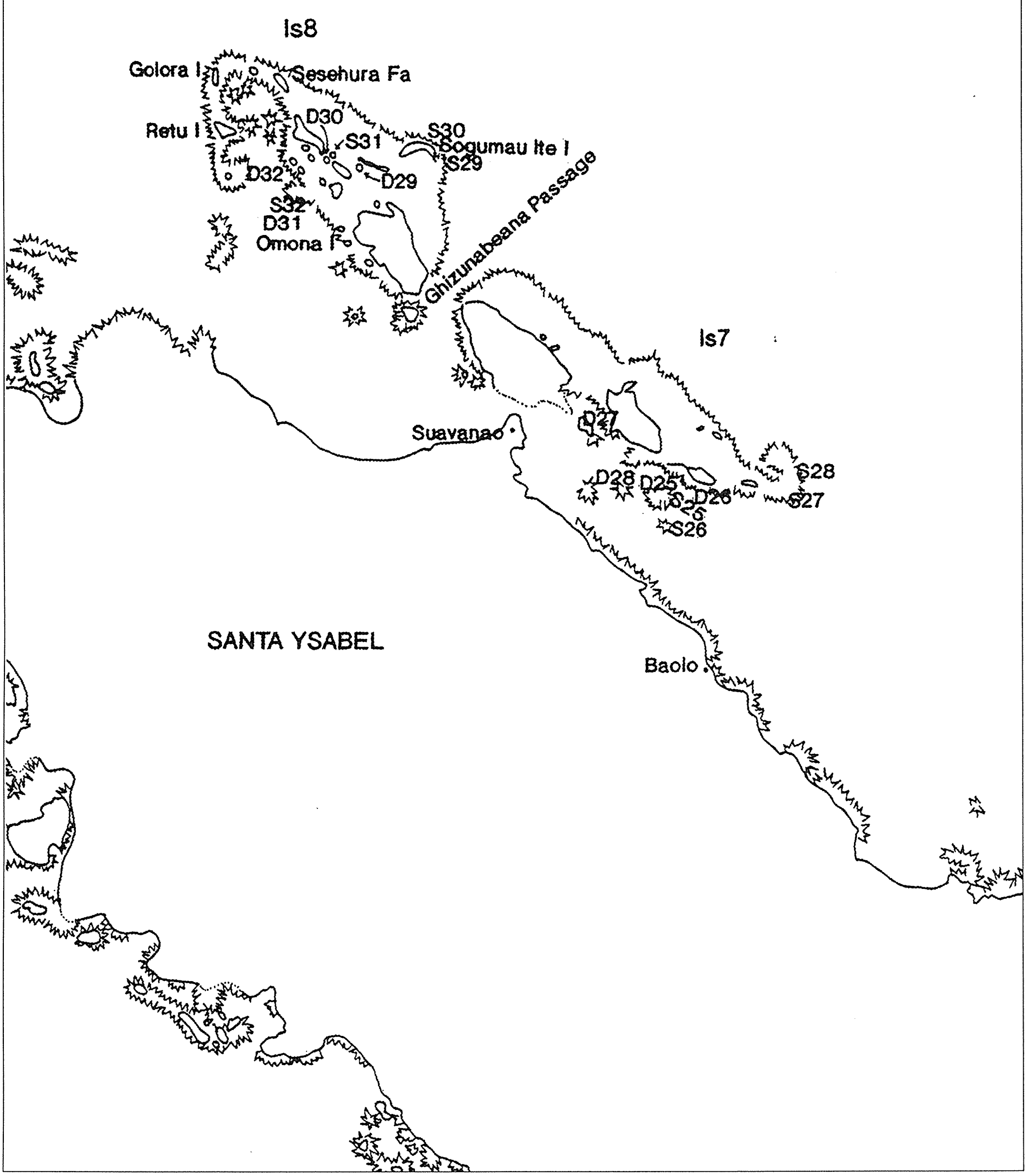

MAP I
WAGHENA ISLAND
Kukutin
Arariki
Nikomaroro
S5
D5
S6
D6
S7
D7
S8
D8
Is2
Silapasope I
D2
S4
Sunda I
D1 S1
S2
Ondolou I
Is1
D4
D3
S3
Ghire I
SOLOMON ISLANDS
Choiseul
Arnavon Islands
New
Georgia
Group
Santa Ysabel
Guadalcanal


MAP II
Laieana Rk
Is3
S11
D11
D12
S10
S9
D10
D9
S12
Sikopo I
Is4
S16
D15
D16
Kerehikapa I
D14
D13
S13
S15
Maleivona I
S14
ARNAVON ISLANDS

MAP III


Parelpoga I
D23
Kologlo I
S23
D24S24
S21
D22
S22
D21
Is6
Malakobi I
Kohirio I
D19
Is5
D20
D18
D17
S17
Sibau I
S18
S19
S20
Nohabuna I
YSABEL GROUP

MAP IV



Is8
Golora I
Sesehura Fa
Retu I
D30
S31
S30
Sogumau Ite I
S29
D32
D29
S32
D31
Omona I
Ghizunabeana Passage
Is7
Suavanao
D27
D28
D25
D26
S25
S28
S27
S26
SANTA YSABEL
Baolo

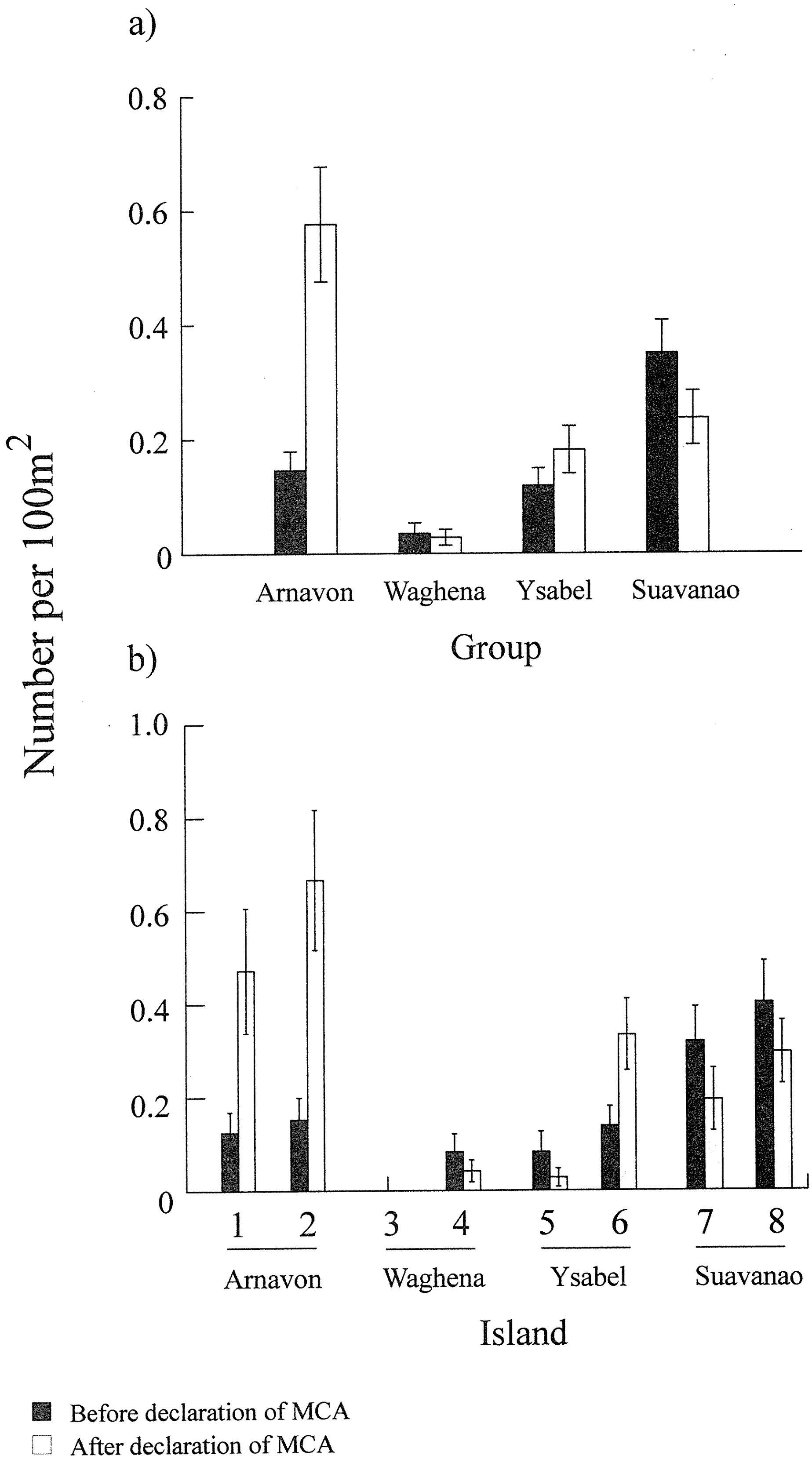


Figure 2a,b.. a) Mean abundance (± SE) of *Trochus niloticus* at each group(n=144), before and after the declaration and b) between islands withineach group (n=72), before and after the declaration.

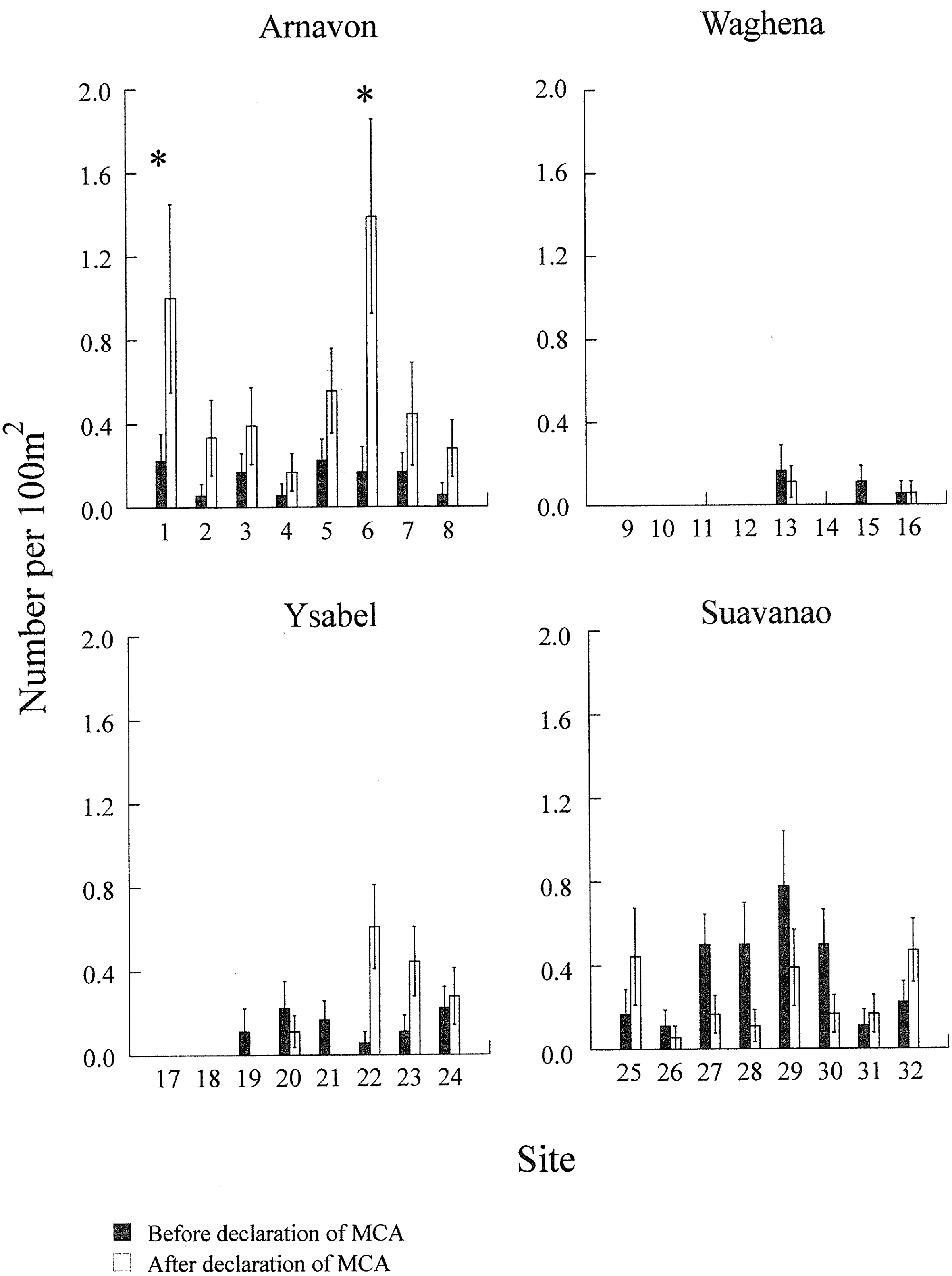


Figure 2c. Mean abundance (± SE) of *Trochus niloticus* at each site (n=18), prior to and after the declaration of the MCA. * indicates significant differences, as identified using SNK tests.

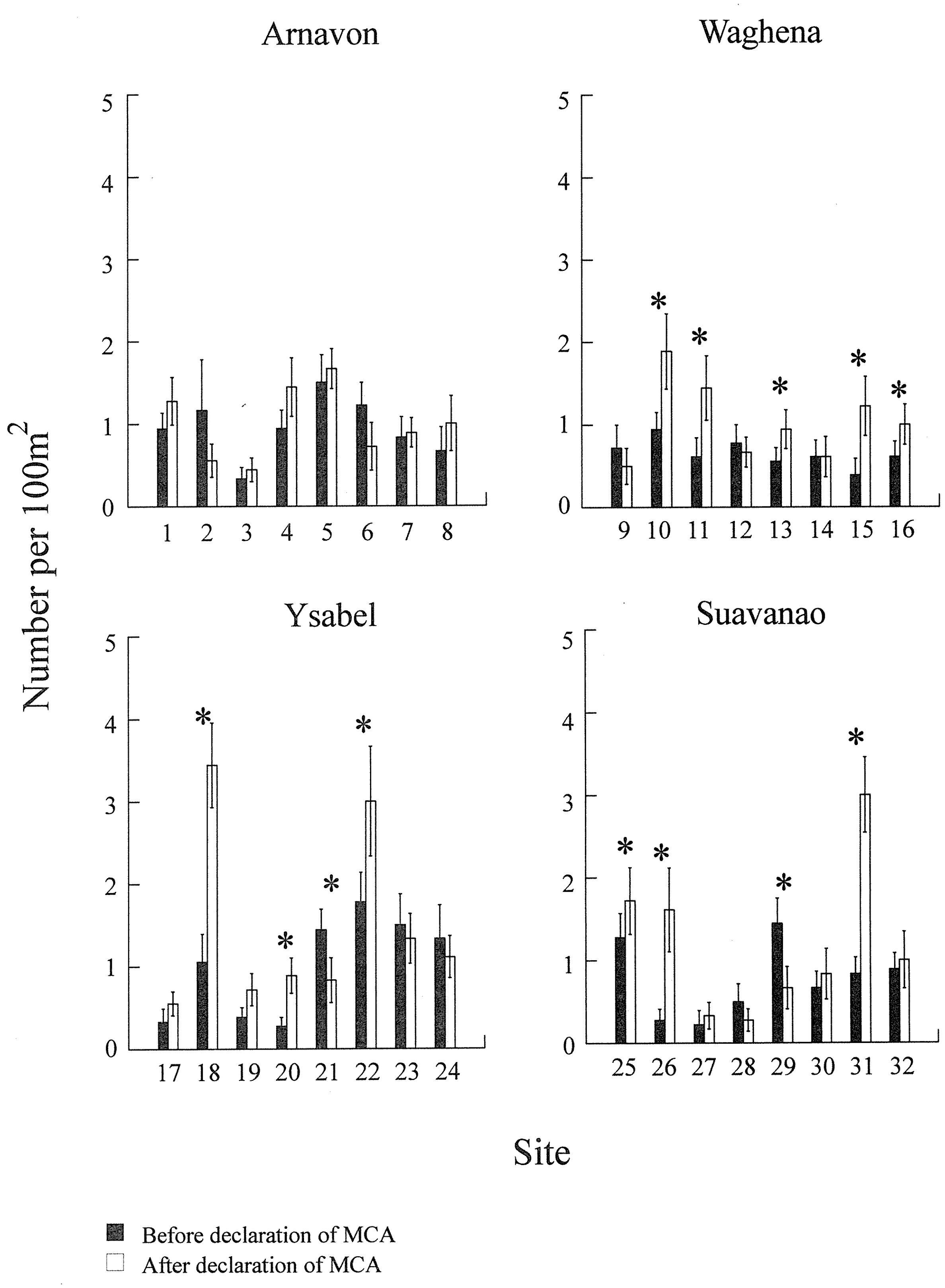


Figure 3. Mean abundance (± 1SE)of *Tectus pyramis* at each site (n=18), before and after the declaration of the MCA. * indicates significant differences, as identified using SNK tests.

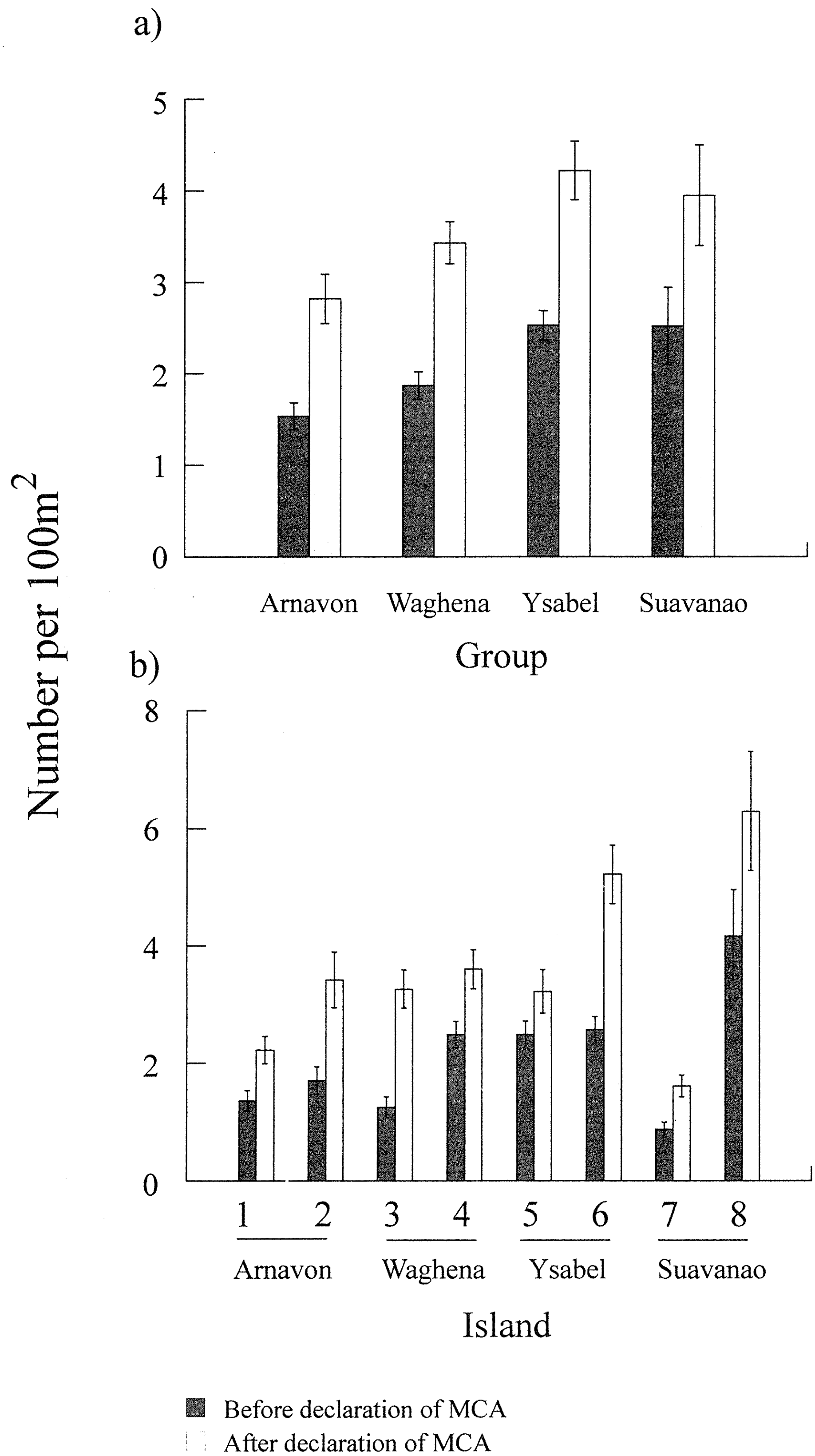


Figure 4a, b. a) Mean abundance (± SE) of all clam species at each group (n=144), before and after the declaration and b) between islands within each group (n=72), before and after the declaration, of the MCA.

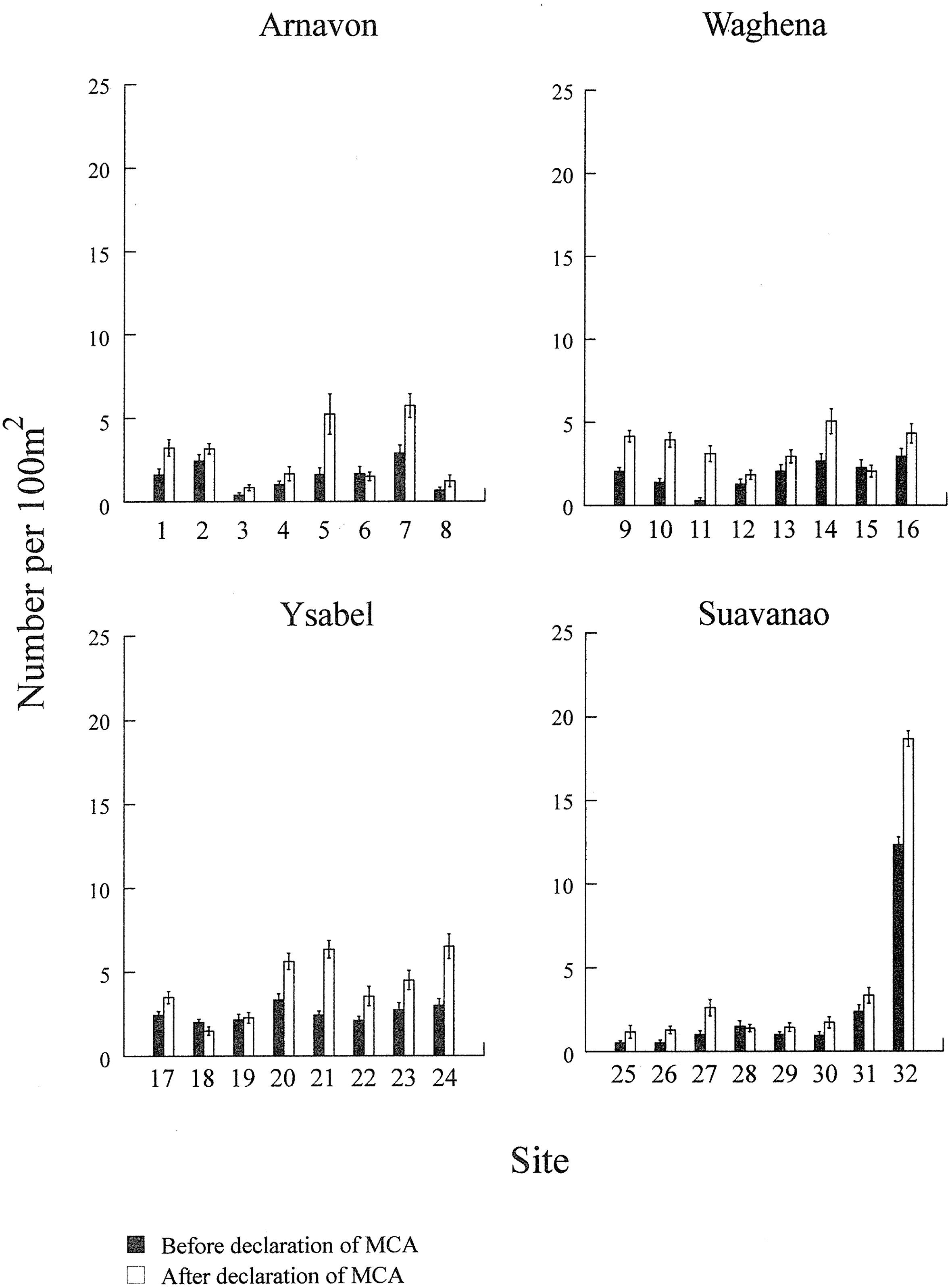


Figure 4c. Mean abundance (± 1SE) of *all calm species at each site* (n=18), before and after the declaration of the MCA.

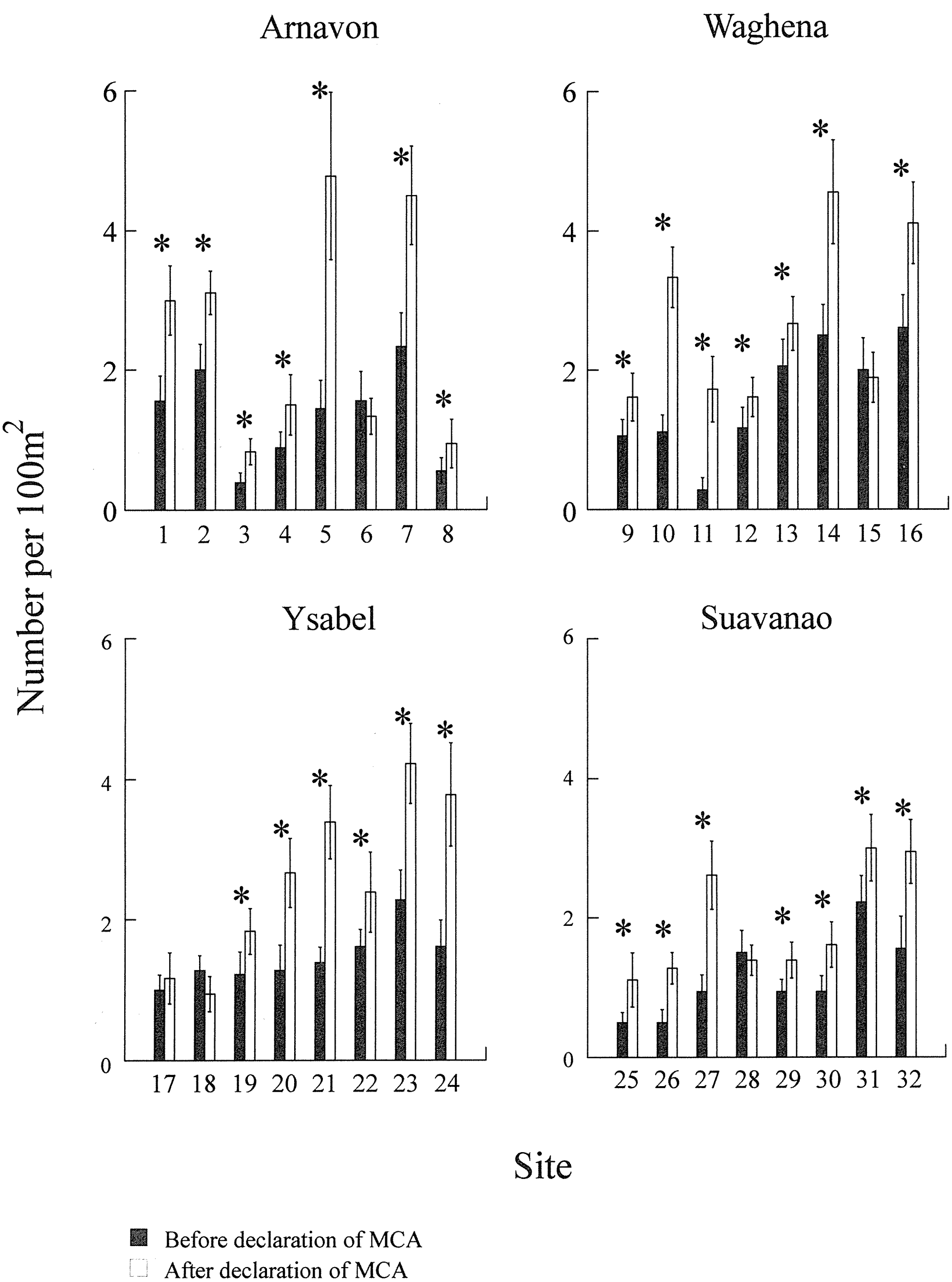


Figure 5. Mean abundance (± SE) of *Ttidacna maxima* at each site (n=18), before and after the declaration of the MCA.

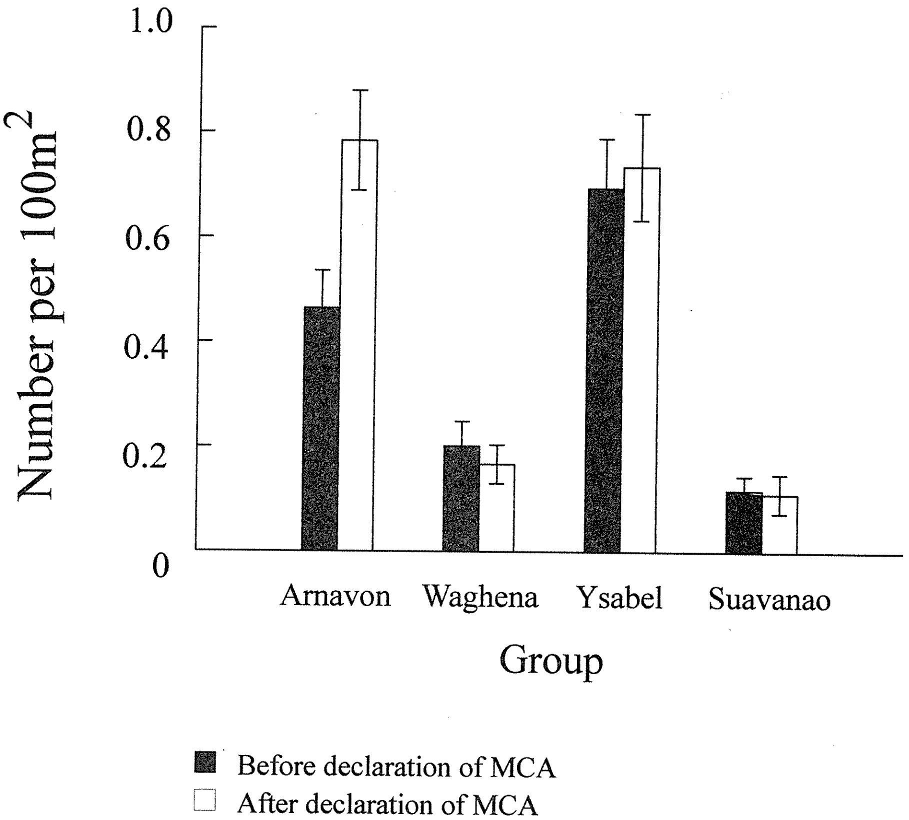


Figure 6. Mean abundance (± SE) of all holothurians in the shallow habitat at each group, before and after the declaration of the MCA (n=144).

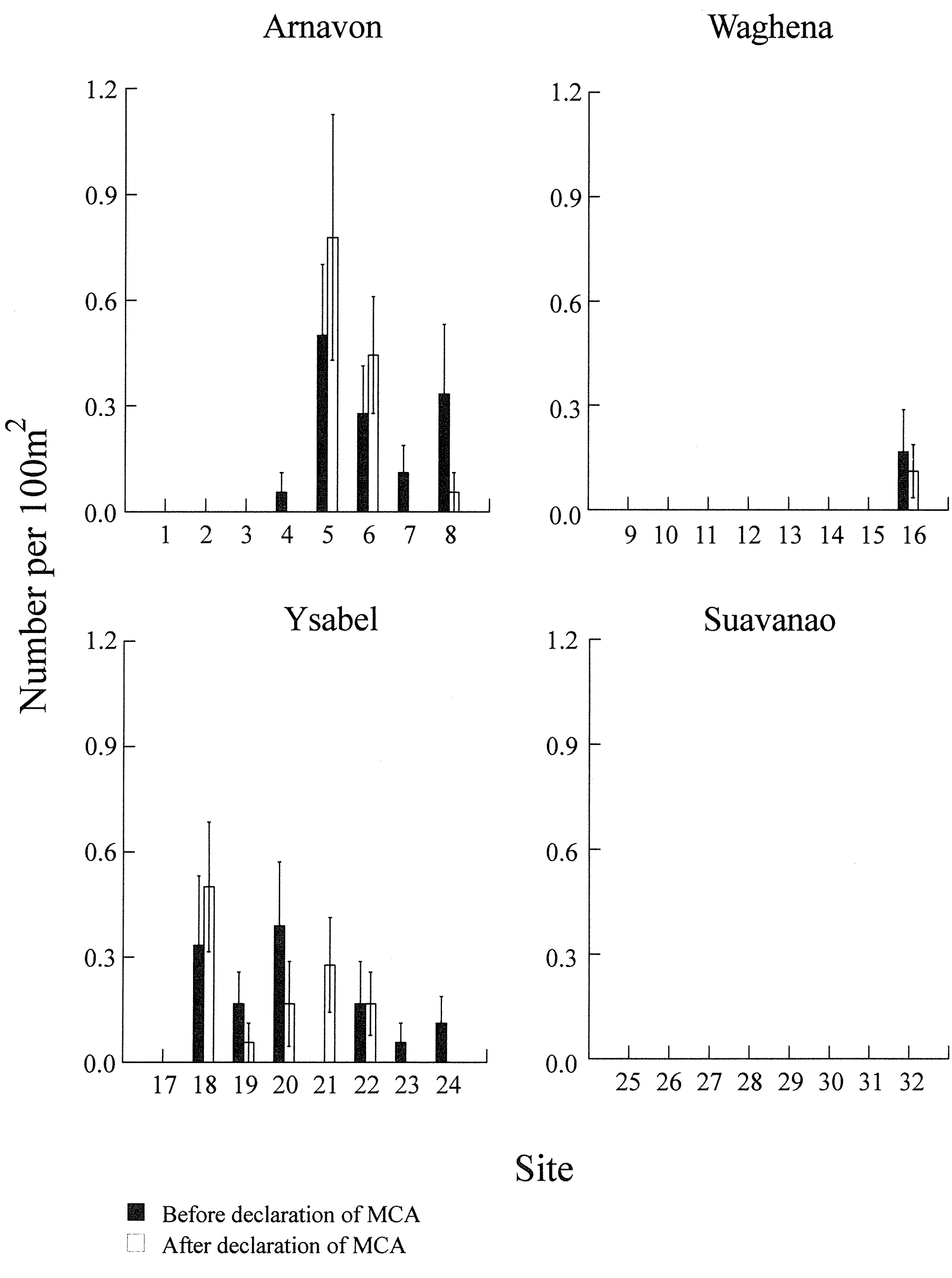
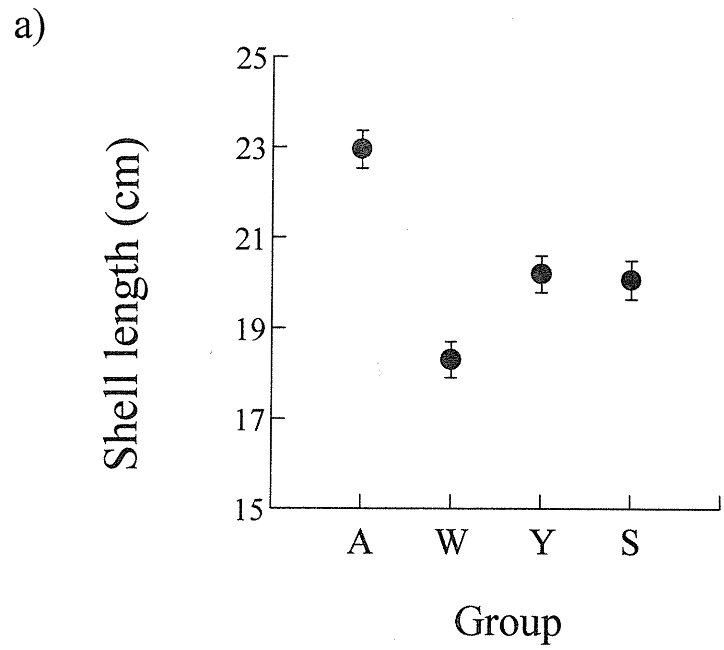


Figure 7. Mean abundance (± 1SE) of greenfish at each site, prior to, and after the declaration of the MCA.



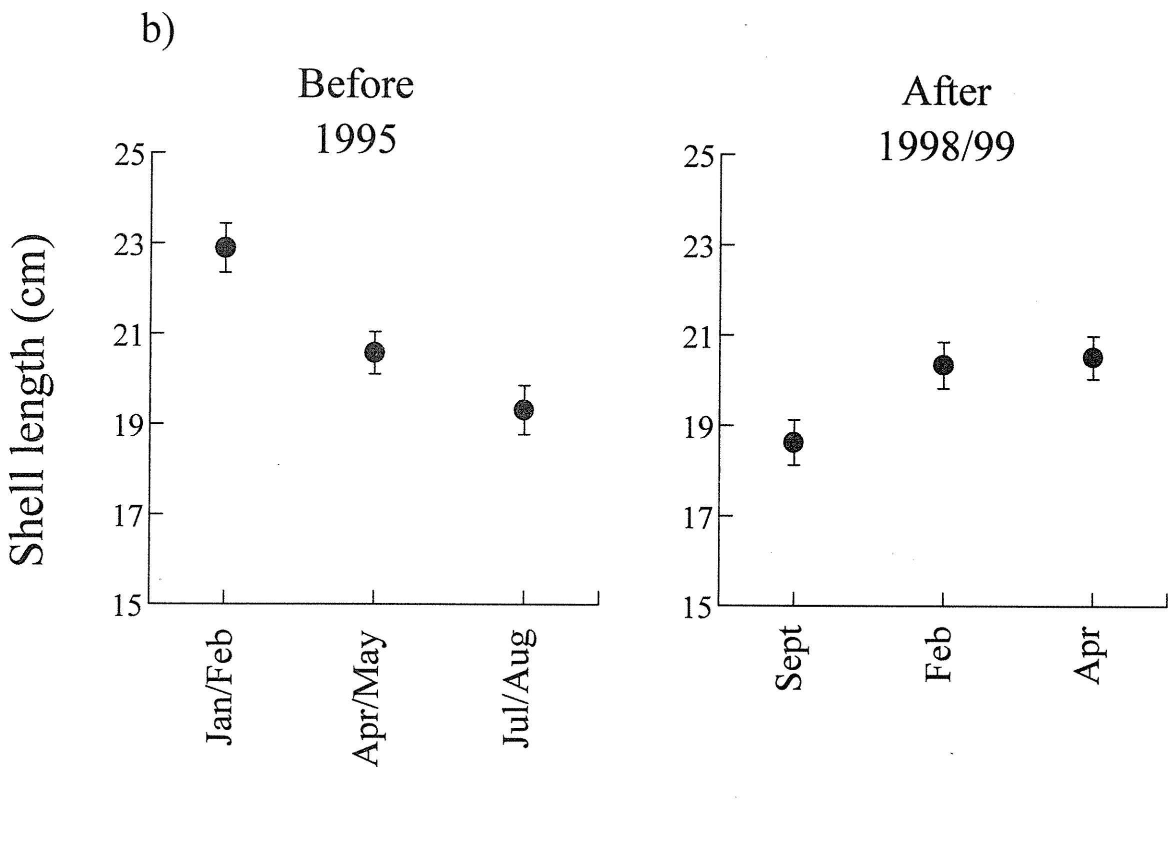


Figure 8a, b. Mean shell length (± SE) of Tridacna maxima a) among groups and b) among times sampled before and after the declaration of the MCA (NB data pooled across all groups). A=Arnavon, W=Waghena, Y=Ysabel, S=Suavano, n=47.

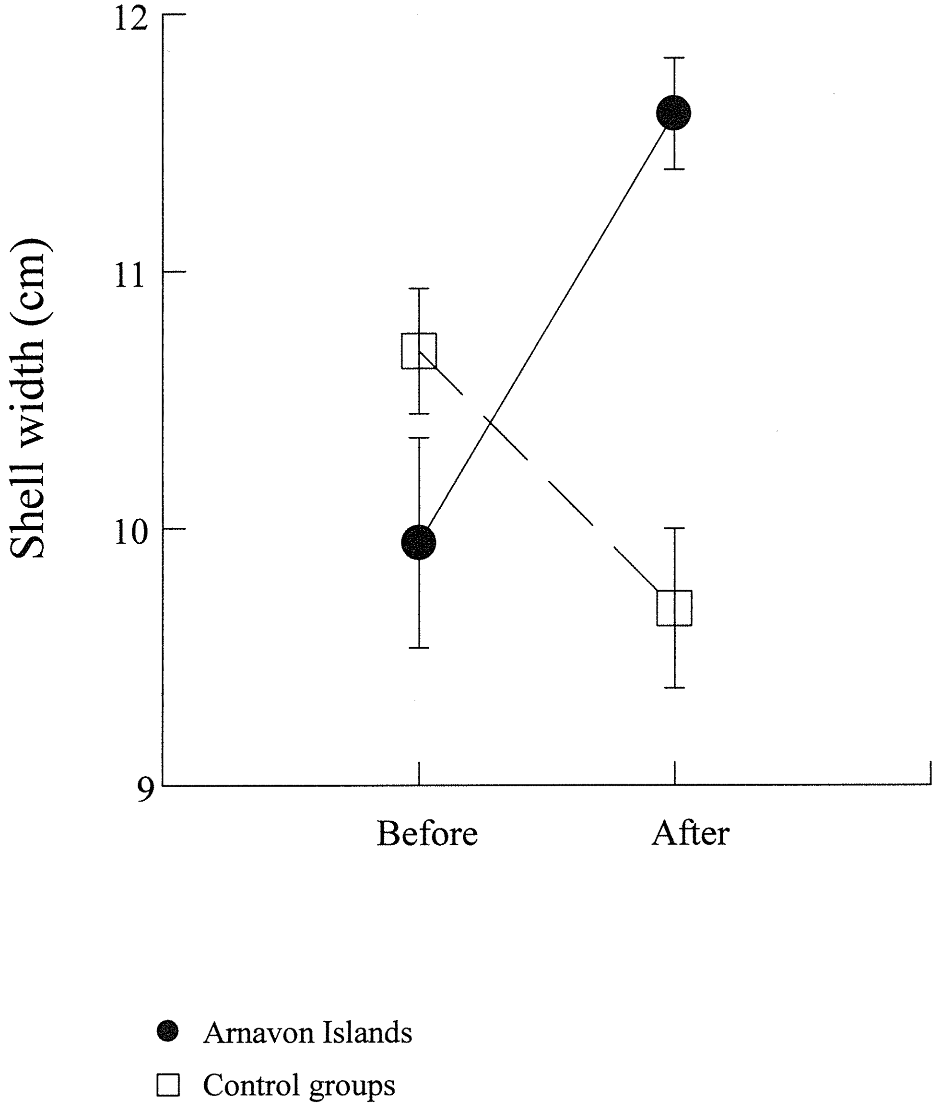


Figure 9a. Mean shell width (± SE) of *Trochus niloticus* at the Arnavon Islands and control groups before and after the declaration of the MCA. n=33.

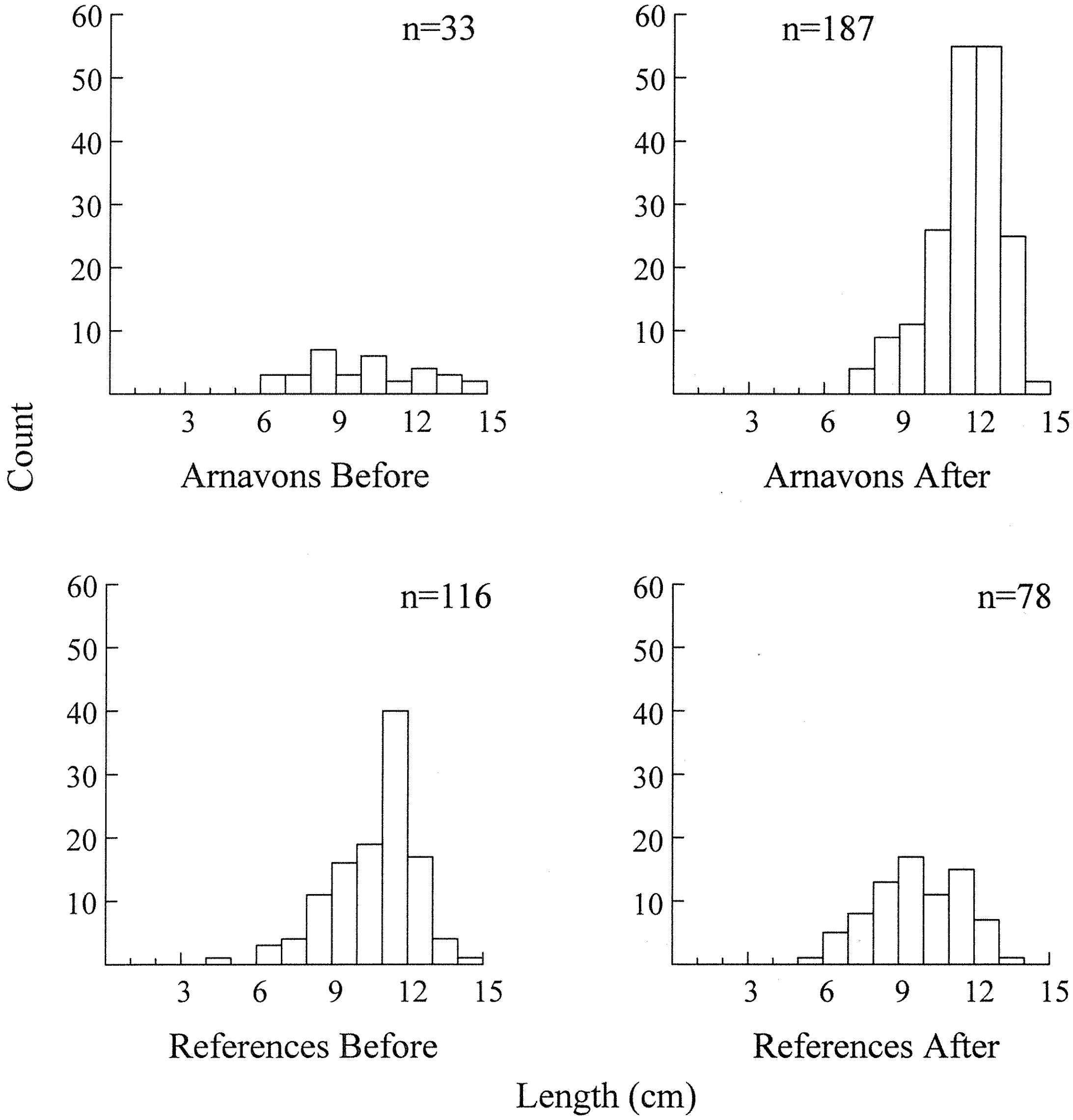


Figure 9b. Length frequency historgrams for *Trochus niloticus* at the Arnavon Islands andreference groups before and after the declaration of the MCA. Data are pooled across the three times sampled before and after the establishment of the MCA and across all three reference groups.

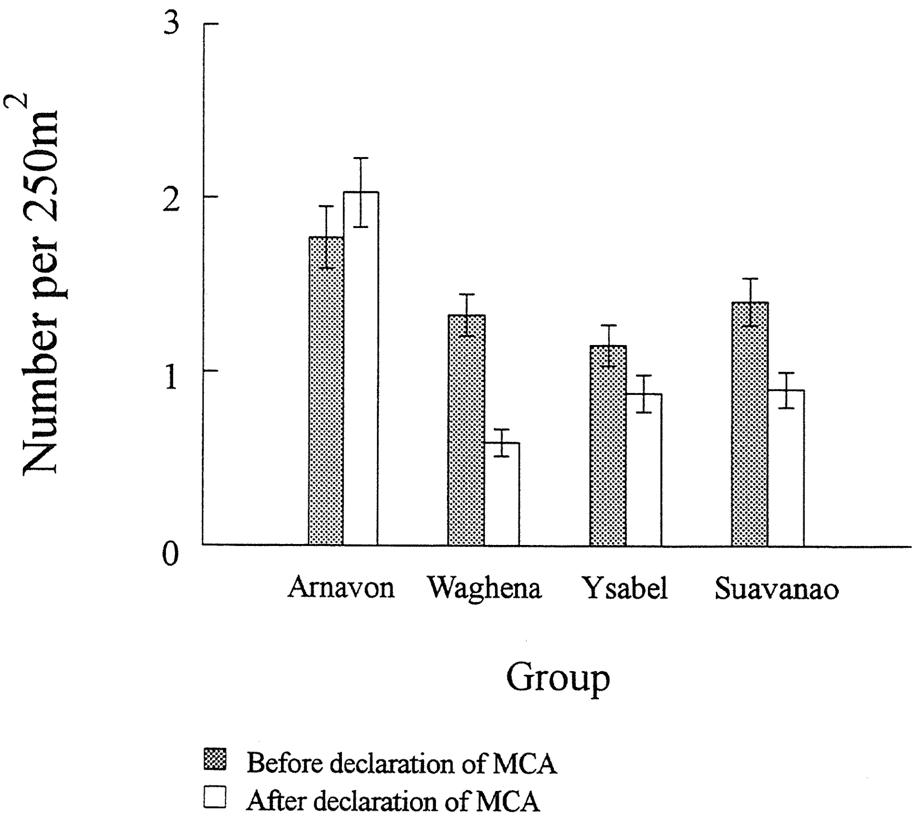


Figure 10a. Mean abundance (± SE) of all holothurians in the deep habitat at each group, before and after the declaration of the MCA (n=144).

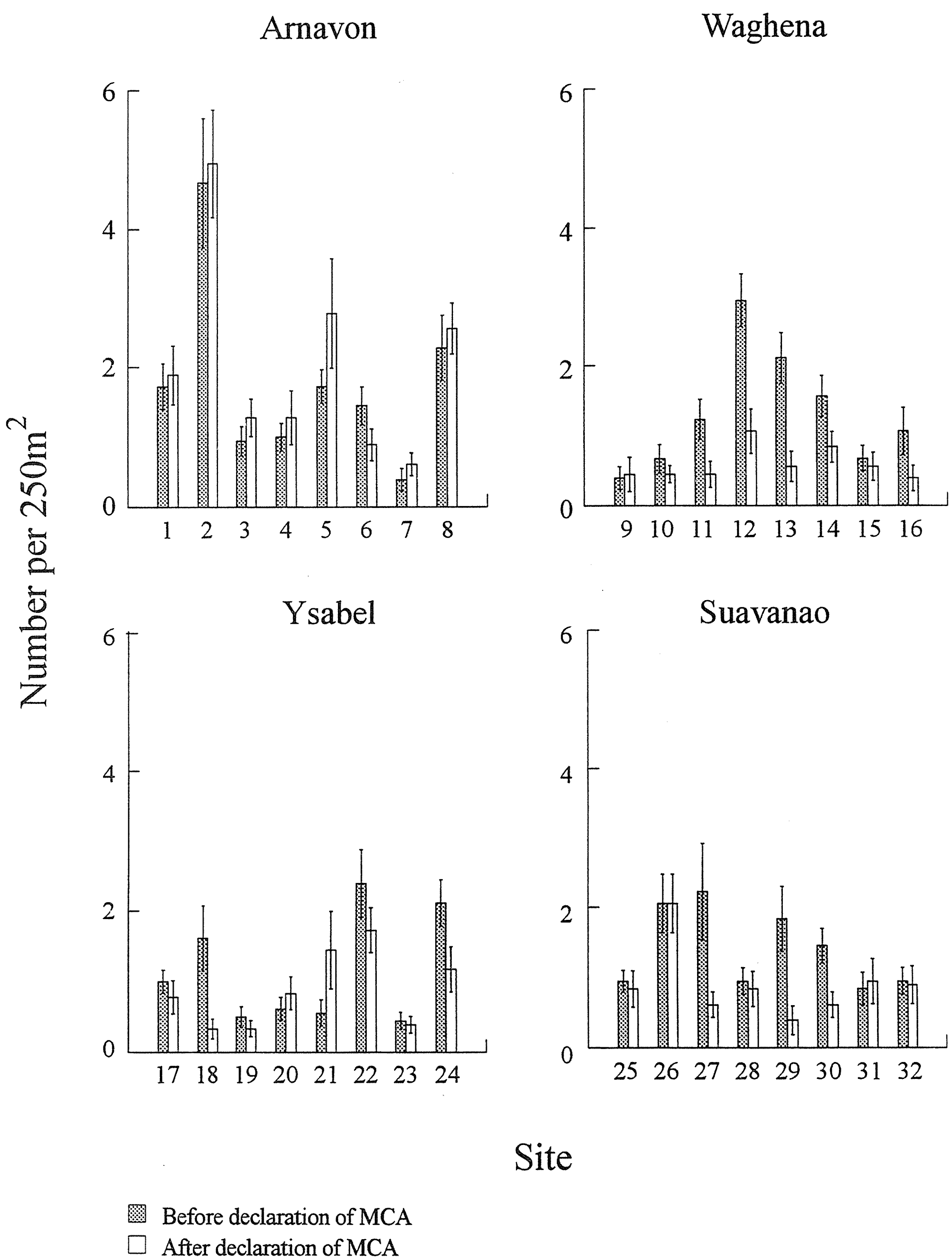


Figure 10b. Mean abundance (± SE) of all holothurians in the deep habitat at each area, ( ) before and after the declaration of the MCA. * indicates significant differences, as identified using SNK tests.

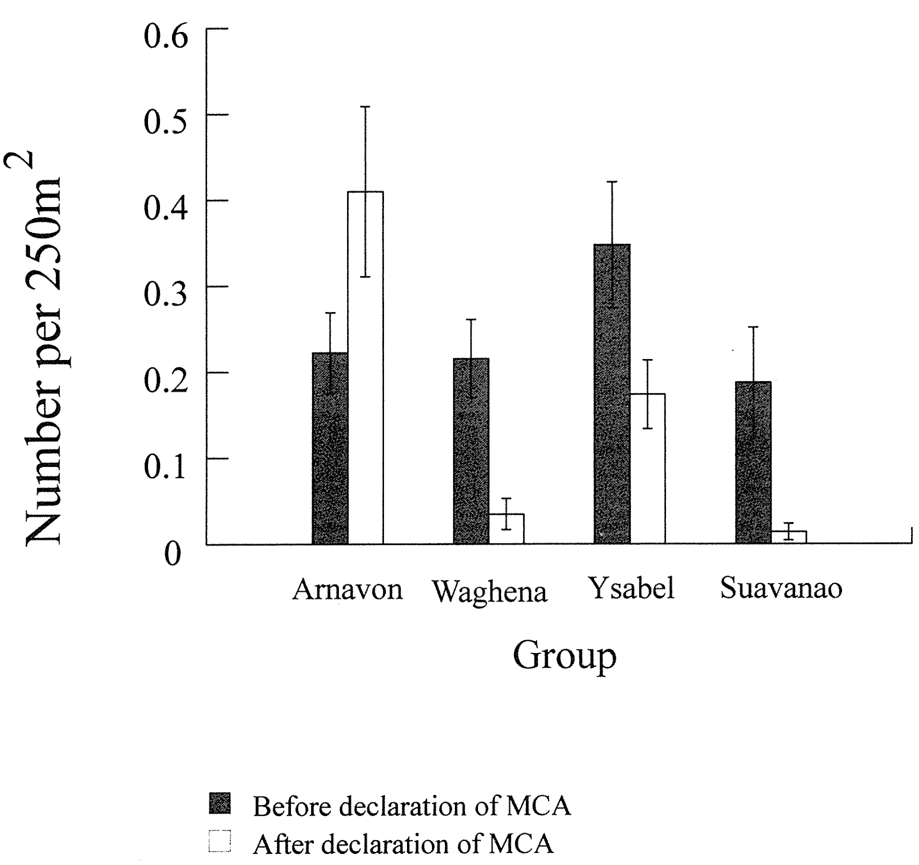


Figure 11a. Mean abundance (± SE) of white teatfish at each group, before and after the declaration of the MCA (n=144).

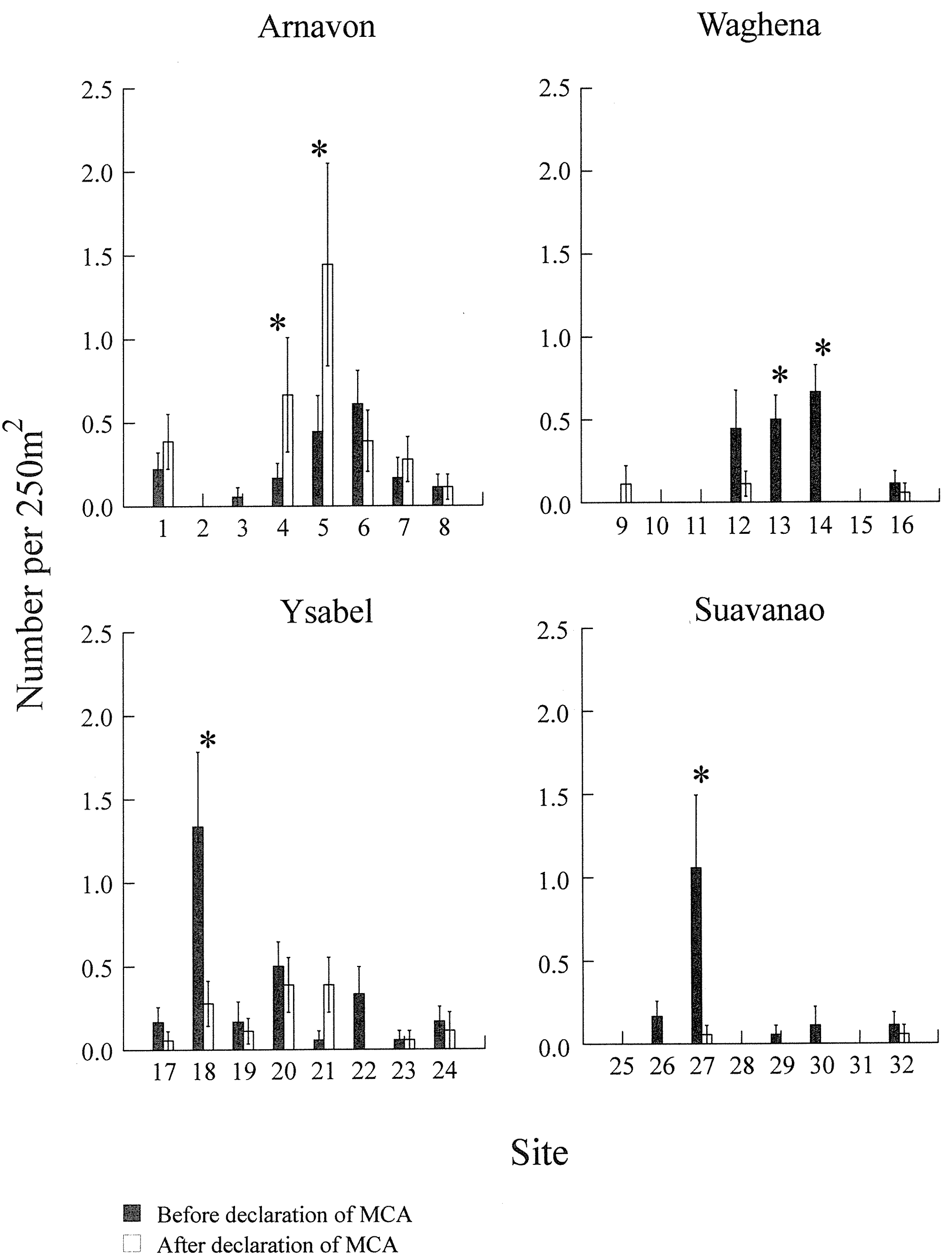


Figure 11b. Mean abundance (± 1SE) of white teatfish at each site, before and after the declaration of the MCA (n=18).

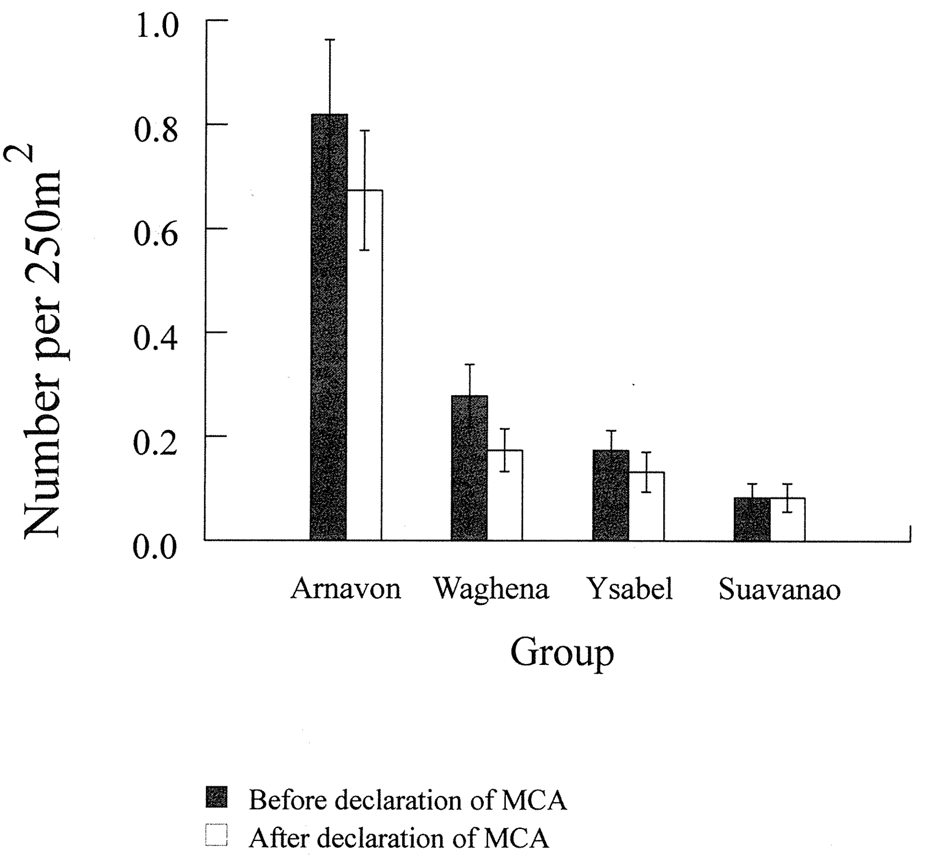


Figure 12. Mean abundance (± SE) of lollyfish at each group, before and after the declaration of the MCA (n=144).

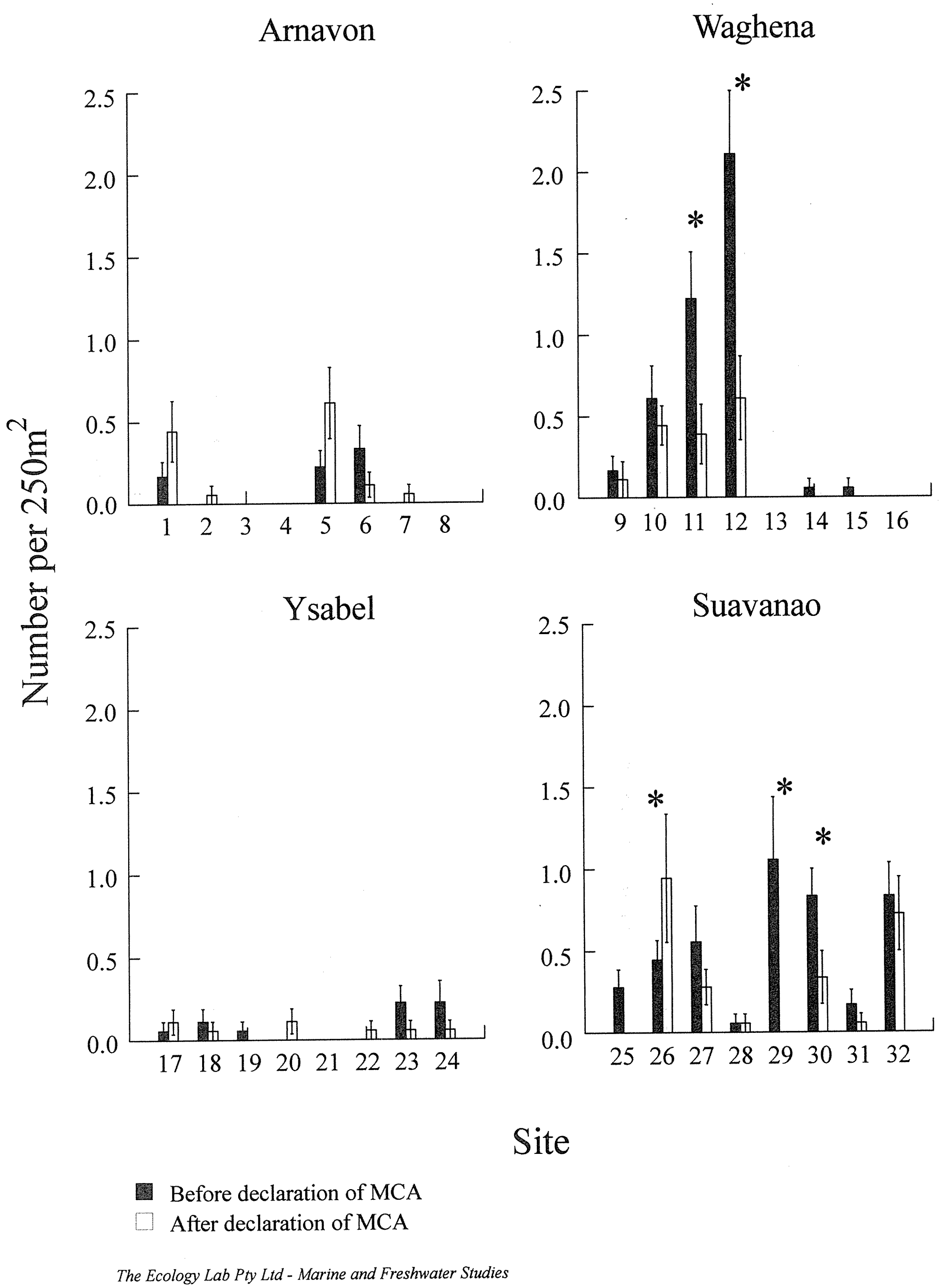


Figure13. Mean abundance (± 1SE)of amberfish at each site (n=18), before and after the declaration of the MCA. * indicates significant differences, as identified using SNK tests.

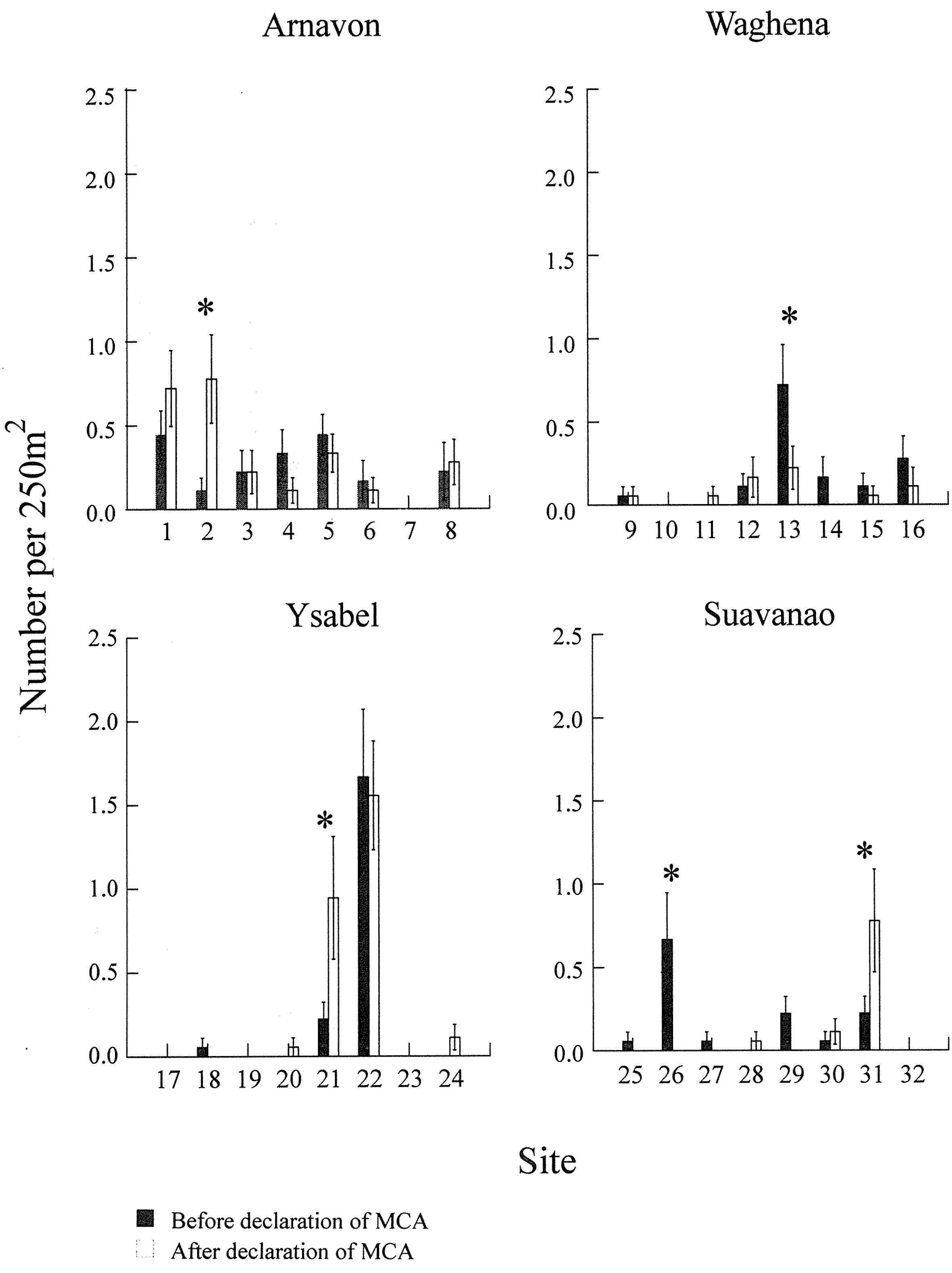


Figure14. Mean abundance (± SE) of elephant trunk fish at each site (n=18), before and after the declaration the MCA.

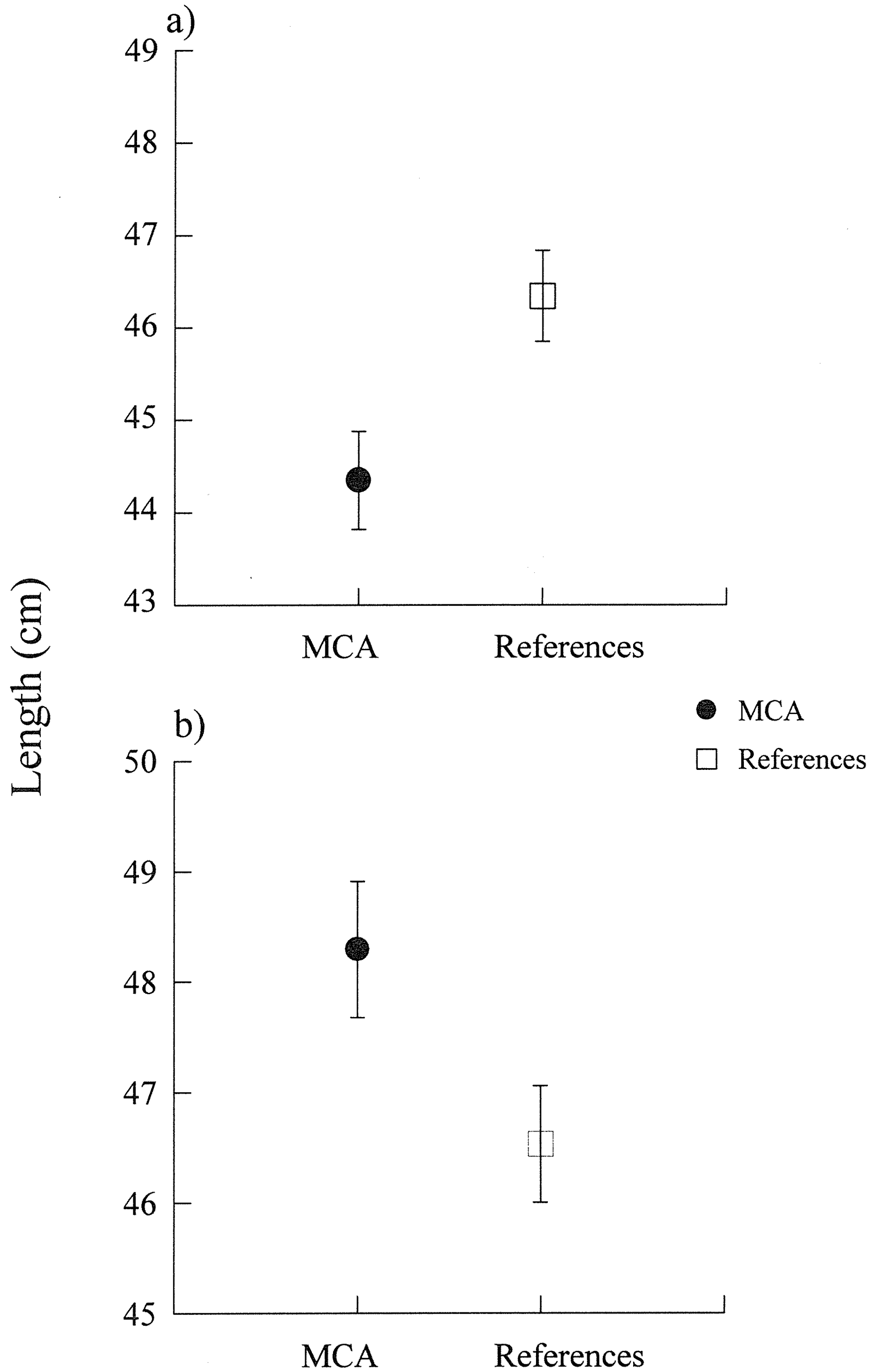


Figure 15a, b. Mean length (± SE) of lollyfish (n=69) and elephant trunk fish (n=40) at the MCA and at the reference areas before and after the declaration the MCA.

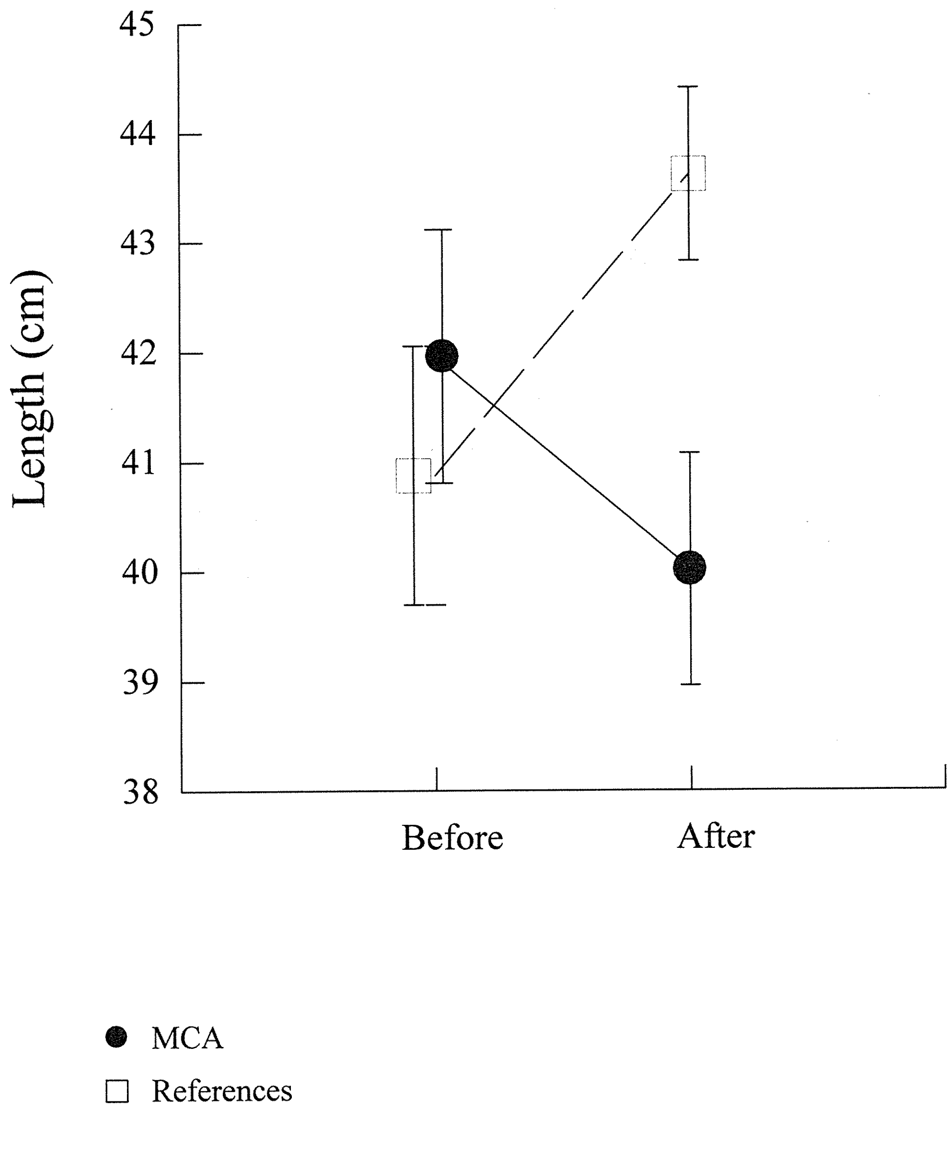


Figure 15c. Mean size (± SE) of lwhite yeatfish at the MCA and at the reference areas before and after the declaration the MCA. n=35.

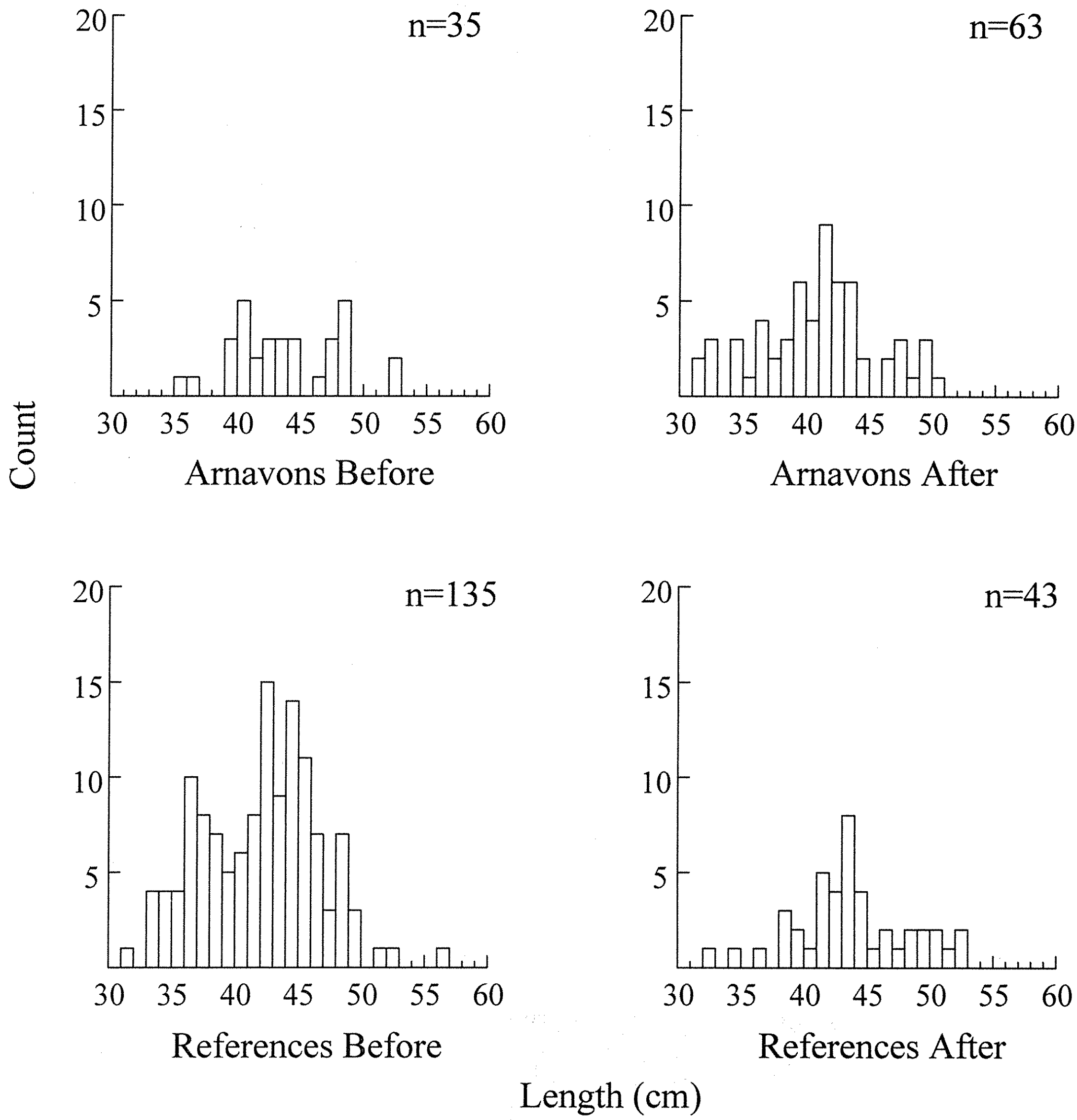


Figure 15d. Length frequency histograms for white teatfish at the Arnavon Islands and reference groups before and after the declaration of the MCA. Data are pooled across the three times sampled before and after the establishment of the MCA and across all three reference groups.

APPENDIX

ARNAVON

Kinetica TES 2001

News

Copy 1.

October 1999

Volume 1: Issue 1

A Newsletter of the Arnavon Marine Conservation Area

Prosecution of Poachers from the Arnavons

The law may work slowly, but in the end we have high hopes that it will work. The project has been frustrated by the difficulties we have had bringing the outstanding poaching cases to justice. Conservation Officers have fulfilled their duties by collecting evidence against those few individuals who have felt free to break both the law and the community's commitment to the Conservation Project. The local police have traveled several times across open waters to take statements, make charges, and notify individuals about court dates. The only place where the system had failed us was the lack of the presence of a magistrate to hear the cases. We were very happy to hear the news last May that a magistrate was coming to Kia to hear cases that included some of those from the AMCA. Magistrate Dwayne Tigulu traveled all the way from Honiara to hear these outstanding cases. He held court in the unfinished new church building in Kia. Unfortunately, the accused did not make the effort to respond to the lawful summons to court. Magistrate Tigulu was not happy about this obvious disrespect being shown toward his office and the laws of the Solomon Islands. It is human nature for people to hope that if they just ignore unpleasant situations for a long enough time, the unpleasantness will just go away. Well this is not going to happen. The Magistrate issued warrants for those people who had been previously charged and were told to be present for court. Prosecution will go ahead, even on cases that took place during the first year of the project, 1995. These few selfish individuals will be called to answer for their crimes, and hopefully with a punishment strong enough to send a message to others that this is not a minor wrong. These few selfish people seek to benefit from the hard work of others and their community's concern for the future. These poachers seem to think that everyone else has sacrificed their rights to the resources in the AMCA so that a few lawbreakers can go in and steal what truly belongs to all of the people of Kia, Wagina, and Katupika. Their actions threaten the continued support of the AMCA project and the potential benefits that may be shared by all community members. A Magistrate will be coming again to Kia in November. He will hear both those cases that were called last May as well as more recent cases in which charges have just been filed. Justice will take place and people will be held accountable for actions that violate the rights and laws of the peoples of the Solomon Islands.

Photo: Conservation Officers of the AMCA remove illegally harvested trochus from a canoe caught in the Arnavon Islands. The case and evidence will be presented at the hearings next month in Kia during the Magistrate's visit.

Outstanding cases are the following:

Date charged	Individuals
23 – 12 – 95	Bero Karotu
	William Aberam
	Tabora Tabutoa
18 – 5 – 96	Teuba Iakobo
	Tiaon Nawaia
	Tokova Nawaia
	Nituru Teibaitoi
	Andrew Bakarewe
20 – 9 – 96	Andrew Bakarewe
	Baibai Matakite
	Barren Matakite
	Teteburi Etekia
20 – 5 – 97	Teika Tutana
	Barren Matakite
	Raba Teika
6 – 5 – 98	John Korea Laone
	Nathan Laone
	Ierimoa Morris
	Aram Taakaria
6 – 8 – 99	Teang Tuake
	Michael