The Shallow-water Echinoderms of Yap

Results of a Survey Performed 27 July to 9 August 2007, Including a Stock Assessment of Commercially Valuable Species

A Report Prepared for the Director of Resources and Development, Yap State, Federated States of Micronesia

Submitted by

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Kammagargab!

EXECUTIVE SUMMARY

Yap has an abundance of commercially valuable species of holothuroids (sea cucumbers) and is currently being targeted by at least three foreign buyers of the processed product, beche-de-mer. The Yap State government has realized the danger of overharvesting this valuable resource and is currently seeking to develop a management plan that will permit a sustainable level of harvesting. We performed a survey of holothuroids and other echinoderms around the main island to 1) assist in a stock assessment of commercially valuable species and 2) document Yap's echinoderms as part of a global survey of coral reef biodiversity. In a total of nine days of surveying, 19 sites were visited around the island. Several commercially valuable species of holothuroids inhabited Yap's waters, some in abundance. The most valuable species seen were *Holothuria* (*Microthele*) *whitmaei* (trade name: black teat fish), *Holothuria* (*Metriatyla*) *scabra* (sand fish) and *Thelenota ananas* (prickly red fish). A total of 66 taxonomic units attributable to species have now been identified from Yap's waters: 33 holothuroids, 14 echinoids, 14 asteroids and 5 crinoids. At least four (12%) of the holothuroids are in all likelihood new to science and formally undescribed. Based on our brief survey, our preliminary recommendations for a beche-de-mer management plan include: 1) Institute a moratorium on fishing until a management plan is in place. 2) Conduct an inventory of the island's commercially valuable species. 3) Institute minimum harvestable lengths for each species. 4) Institute temporary closures to increase stock size and value. 5) Increase public awareness and teach monitoring methods to villages. 6) Continually assess the effectiveness of the management plan and modify it when necessary. We discuss all these measures at greater length in the report.

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INTRODUCTION

In early 2007, we submitted a letter to the Director of Marine Resources, Yap State, expressing our interest in surveying and collecting holothuroids (sea cucumbers) on Yap. The proposed survey was to form part of our U.S. National Science Foundation-sponsored efforts, in collaboration with other holothuroid taxonomists worldwide, to document the global diversity of aspidochirote holothuroids inhabiting coral reefs. We were informed that our proposal was most timely, as some villages had recently begun selling commercially valuable species of holothuroids from their reefs to foreign buyers who were shipping the animals to Asian markets as processed beche-de-mer. In light of this revelation, we quickly refocussed our proposed surveys from a solely research-oriented format to one emphasising rapid, low-tech methods useful for community-level assessment of commercially valuable stocks.

From 27 July to 9 August 2007, we surveyed the holothuroids and other echinoderms around the island of Yap. During this period, we

- surveyed 19 reef sites around the island for their echinoderm fauna,
- assembled a checklist of the island's echinoderms,
- collected and preserved voucher specimens of each species,
- photographed vouchers or representative specimens of each species,
- recorded the population size structure of commercially valuable species of holothuroids,
- taught methods of stock assessment to personnel at Marine Resources,

- interviewed stakeholders to learn their concerns about the development of a beche-de-mer industry,
- presented a seminar to community stakeholders on our preliminary findings and, finally,
- distributed a preliminary report that included preliminary recommendations about safeguarding holothuroid resources, to the Governor, Director of Resources and Development and stakeholders.
- presented this final report to the Director of Resources and Development.

At least two other types of work products also should be anticipated, with various timelines to completion:

- An illustrated field guide to the island's holothuroid fauna, primarily as a tool for personnel at Marine Resources. This should take about six months to complete.
- Peer-reviewed scientific publications, to include, minimally, the first comprehensive faunistic treatment of the island's echinoderms and the formal taxonomic description of at least one species new to science. These publications will be completed over the course of one to two years.

The following report outlines a simple method for stock assessment and provides several suggestions for managing beche-de-mer based on our analysis of the data and the published literature. Following this, we provide a provisional checklist to the island's echinoderms, then discuss the scientific significance of these findings. The term "provisional" indicates that the checklist consists of identifications of specimens made in the field. Hence, a few of the designations will, in all likelihood, change, or in instances where a species could not be immediately assigned, even provisionally, species' identities will be clarified after full laboratory examination. Still, most species designations provided here are trustworthy and thus, on whole, the list is useful for scientific and public discussion of Yap's echinoderms, particularly holothuroids, now under harvesting pressure. Indeed, as far as we know, this is the first attempt at a comprehensive compilation of Yap's echinoderms.

METHODS

Site selection

Sites (Figure 1) were selected for their even distribution around the island and their presumed high diversity of echinoderms. GPS coordinates of each site were recorded. Several sites where harvesting of holothuroids was known to have occurred (primarily along the east coast of Maap) were avoided, as the goal in the limited time available was to assess virgin stocks of the harvested species. Most major shallow-water marine habitats were investigated, including reef flats, "blue holes," forereef slopes to 25 m depth, seagrass beds, channels and areas adjacent to mangroves. Given the time constraints, we eschewed mangrove channels, rivermouths, steep drop-offs and elsewhere with little accumulation of well-sorted sediment, since such areas, while in some cases having a possibly rich echinoderm fauna (e.g., crinoids and dendrochirote holothuroids in the case of drop-offs), were likely to have few commercially valuable holothuroids, one focus of the survey.

Stock survey

Divers performed counts of commercially valuable species of holothuroids using timed haphazard swims, usually between one or two hours. In addition, divers recorded the undisturbed lengths of animals *in situ*. This approach was reasoned superior to transects, quadrats or manta tows for several reasons. First, the usual methods are time intensive and our mandate was to perform a large-scale survey in a limited period. Second, our approach also estimated an important quantity of interest to fisheries

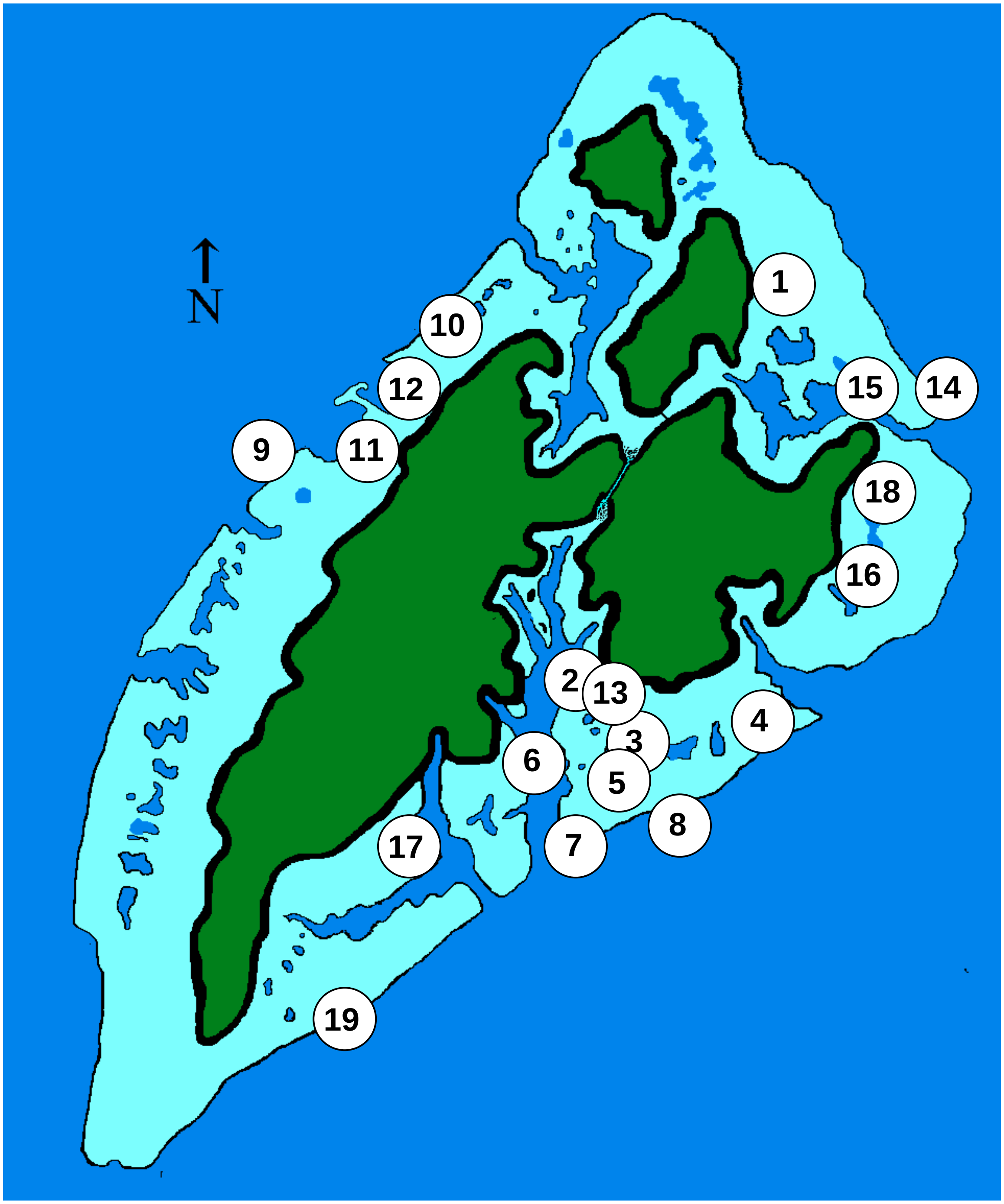

Figure 1. Survey sites around Yap main islands: 1) North of Wacholab, Maap 2) O'Keefe's (BIY) 3) Tamil blue hole 4) Peelak Channel, South 5) Tamil blue hole 6) Woneeday Channel, North 7) Woneeday Channel, South, outer reef flat 8) Tamil reef slope, "The Barge" 9) Gaetmoqon, Weloy, reef slope 10) Yyin 'Ayirech, Fanif, blue hole 11) Gaetmoqon, Weloy, blue hole 12) North of Gaetmoqon channel, Weloy, blue hole 13) O'Keefe's (BIY), mangroves 14) Goognaw Channel, Gagil 15) Riikeen, Gagil 16) Wanyan, Gagil, blue hole 17) Lamear, Rull 18) Wanyan, Gagil 19) Garim, Rull.

managers: catch per unit effort, the number of animals that a fisher might collect per unit time. Moreover, the method can easily be used by villages to monitor their own stocks. Finally, information on length can be translated into initial management recommendations about minimum harvestable size per species.

Calculating minimum harvestable lengths

We calculated minimum harvestable lengths for each abundant species based on the mean length of the sampled individuals. The object of calculating this quantity is to preserve stock in proportion to a conservative percentage of its reproductive capacity. The latter phrase essentially refers to the total number of eggs produced by a stock. Amesbury (1996) suggests conserving 50% of the reproductive capacity of a beche-de-mer stock. However, calculating minimum harvestable length based on this level of conservation requires knowledge of target species' biology, which is currently unavailable for Yap stocks. Relevant aspects of the biology include sex ratio and size class-specific proportion of reproductive females. Still, given the urgency of implementing a management plan and given what *is* known about the relationship between holothuroid length and the unavailable parameters (Amesbury 1996), mean length is probably a reasonable and conservative first estimate until such data can be gathered.

Calculating catch per unit effort

We estimated catch per unit effort (CPUE) for each abundant species at a site during timed swims by three observers. These swims ranged from 40 minutes to 200 minutes. Particularly abundant species at a site were usually only counted for the first 20 to 30 minutes. CPUE was then calculated for a given species at an island level (“pooled CPUE”) by summing over site abundances *n* of all observers and dividing this by the sum of survey times *t* for all sites and all observers:

$$pooled \quad CPUE = \frac{\sum n_i}{\sum t_i}$$

We also calculated for each species the mean site CPUE over all observers and sites *k* at which the species occurred:

$$mean \;\; CPUE = \frac{1}{k}\sum \frac{n_i}{t_i}$$

Biodiversity inventory

Divers also recorded all species of echinoderms that they observed at each site to a maximum of 25 m in depth. Collected specimens, or representatives thereof, from nearly all species were photographed *in situ*. One or two voucher specimens of each species were collected and preserved in 95% ethanol or 70% isopropanol. Before preservation, holothuroids were first relaxed in seawater laced with chlorobutanol and chilled to near freezing. No special methods were used to assess infaunal species; divers fanned sediment to uncover such forms or combed the sediment’s surface for the tests of burrowing echinoids. Divers looked through rubble and in crevices to find cryptic forms. Night snorkels and dives were used extensively as most coral-reef invertebrates, including echinoderms, are nocturnally active and exposed.

RESULTS

In a total of nine days of surveying, 19 sites were visited around the island. In the first subsection below, *Stock survey*, we outline the species composition and ecology of commercially valuable species. In the second subsection, *Catch per unit effort*, we calculate catch per unit effort for abundant species. In the third subsection, *Minimum harvestable lengths*, we calculate minimum harvestable lengths for abundant species. In the fourth and final subsection, *Biodiversity inventory*, we report on the species composition and ecology of other holothuroids and echinoderms.

Stock survey

Several commercially valuable species of holothuroids occurred in Yap's waters (Figure 2). The most valuable species seen were *Holothuria* (*Microthele*) *whitmaei* (trade name: black teat fish), *Holothuria* (*Metriatyla*) *scabra* (sand fish), *Actinopyga varians* (red surf fish), and *Thelenota ananas* (prickly red fish). Some of these species occurred in abundance.

The black teat fish (Figure 2C) occurred infrequently (approximately two to six animals were observed per one-hour swim) on mid- to outer reef flats islandwide. In other parts of Micronesia, this species also is found on the forereef slope to a maximum depth of about 23 m. In older literature, this species goes by the name of *H.* (*M.*) *nobilis*, a name now reserved for a closely related species from the western Indian Ocean.

The sand fish (Figure 2D) was found on the eastern side of the island in seagrass beds adjacent to mangroves (we include here observations by E.

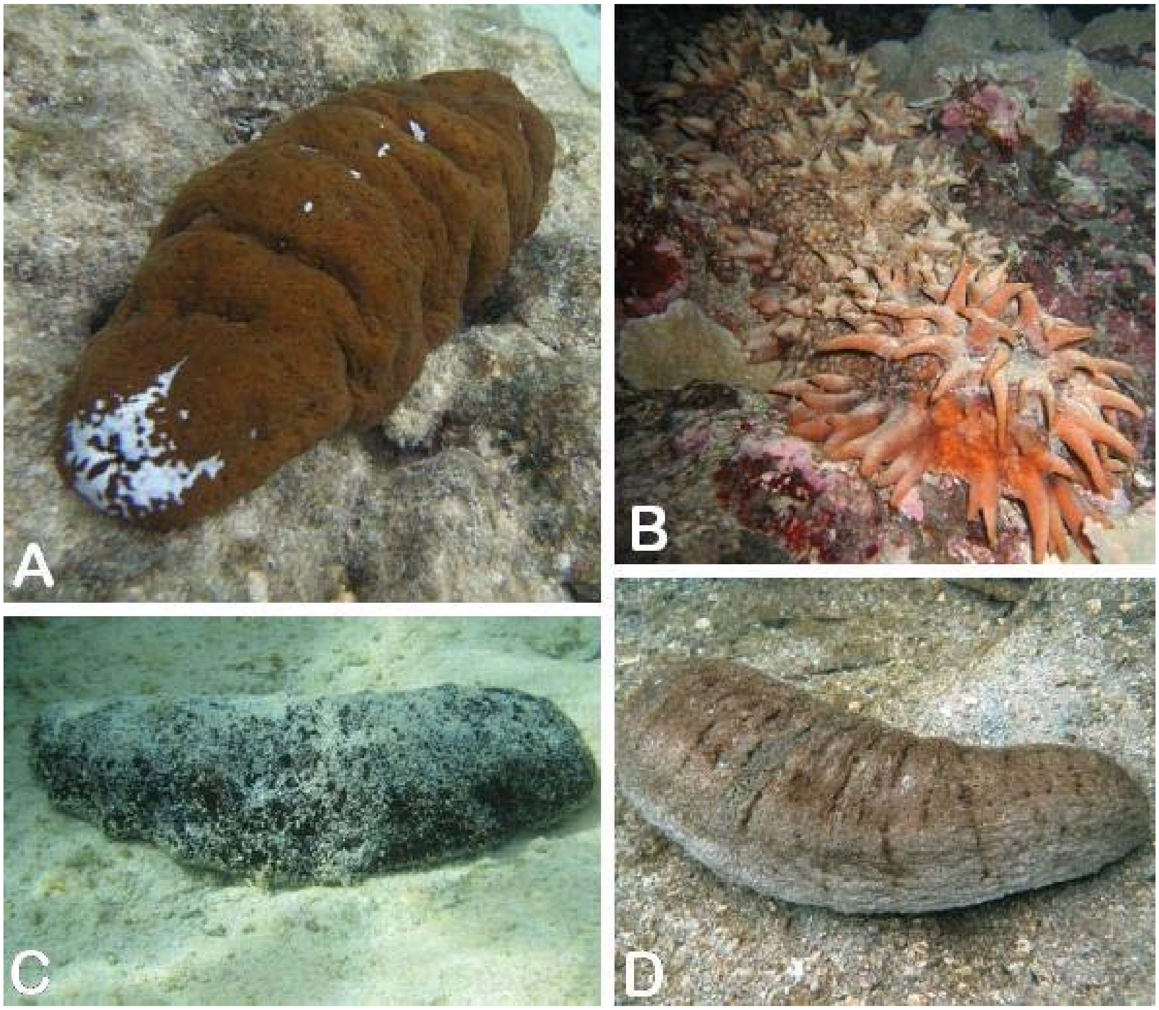

Figure 2. Some commercially valuable species of holothuroids found on Yap. A) *Actinopyga varians.* B) *Thelenota ananas*. C) *Holothuria* (*Microthele*) *whitmaei*. D) *Holothuria* (*Metriatyla*) *scabra*.

Tardy, unpublished). The seagrass/circum-mangrove habitat is typical for this species. It may also occur in this habitat on the western side, though we have not observed it there. We also observed a few individuals of the black form, often called *H.* (*M.*) *scabra var. versicolor*.

The red surf fish (Figure 2A) was only rarely seen. In older literature, this species goes by the name of *A. mauritiana*, a name soon to be reserved for the closely related species from the Indian Ocean (Netchy and Paulay, in preparation). It occurred on the wave-washed reef crest of a minority of surveyed locales (we include here the unpublished observations of E. Tardy, South Pacific Commission). The animal seems typical of others in the western Pacific, with a chestnut colour and variable amounts of white mottling.

The prickly red fish (Figure 2B) was the most widely seen species and found at nearly all sites examined to moderate depths (5-10 m). At each site where it occurred, between one to 12 specimens were seen. Animals were usually quite large and were usually found on sand bottoms, though individuals were still occasionally seen on forereef slopes on rubble or amongst corals.

Other commercial species, however, occurred at moderate to high densities. Hence, an expansion of the island's beche-de-mer fisheries appears feasible. The most abundant commercial species were *Bohadschia argus* (spotted fish), *Bohadschia bivittata* (sand fish), *Holothuria* (*Halodeima*) *atra* (lolly fish), *Holothuria* (*Halodeima*) *edulis* (pink fish) and *Stichopus chloronotus* (green fish).

In sum, Yap appears to have numerous commercially important species of holothuroids that could be harvested in large numbers. How much of these resources can be sustainably harvested is, however, a separate question and will be addressed later in this report under the section *Recommendations*.

Table 1. Catch per unit effort (CPUE) of commercially valuable species of holothuroids on Yap. *n* = number of sites with the species; Pooled = CPUE based on pooling all sites for a species; Mean = mean site CPUE; Min = minimum site CPUE; Max = maximum site CPUE.

Species	*n*	Pooled	Mean	Min	Max
Actinopyga sp nov	2	20.0	163.8	3.6	324.0
Actinopyga varians	1	1.8	1.8	1.8	1.8
Bohadschia argus	10	3.6	4.7	0.6	14.4
Bohadschia bivittata	9	4.2	7.2	0.3	34.5
Bohadschia marmorata	2	4.2	8.3	0.6	16.0
Holothuria (*Halodeima*) *atra*	9	6.3	17.6	0.6	80.0
Holothuria (*Halodeima*) *edulis*	8	9.5	12.4	0.6	48.0
Holothuria (*Microthele*) *fuscogilva*	1	1.8	1.8	1.8	1.8
Holothuria (*Metriatyla*) *scabra*	1	2.6	2.6	2.6	2.6
Holothuria (*Microthele*) *whitmaei*	4	2.8	2.4	0.5	7.1
Pearsonothuria graeffei	3	1.6	1.7	0.5	4.0
Stichopus chloronotus	9	6.4	9.2	0.6	32.8
Stichopus horrens	3	0.5	0.6	0.3	0.9
Stichopus vastus	3	4.1	5.4	2.9	7.2
Thelenota ananas	5	2.5	2.7	0.6	6.9

Catch per unit effort

Table 1. shows catch per unit effort of commercially valuable species for which at least three individuals were measured. A few species seen at several sites are not included. For example, *Holothuria* (*Acanthotrapezia*) *coluber* (snakefish) is of moderate value as beche-de-mer and was abundant at a few sites. However, this species is extremely extensible,

often extending to over a meter in length. In addition, its posterior is invariably wedged in a crevice into which the animal contracts when disturbed, making measurements unreliable.

The pooled CPUE values in Table 1 estimate island-wide CPUE for the species. While this was calculated using only sites at which a given species occurred, the values are probably underestimates, since we sampled haphazardly, while fishers will target areas of highest abundance of a species. The mean CPUE is an average catch per unit effort calculated over sites at which a given species occurred. The minimum and maximum site CPUE are often quite different, indicating wide variability in abundances of a species between sites.

Species in Table 1 found at only a few of the 19 sites surveyed, probably indicate species with more patchy distributions around Yap (e.g., *Actinopyga varians* and *Holothuria* (*Microthele*) *fuscogilva*). Conversely, species such as *Bohadschia argus*, *Holothuria* (*Halodeima*) *atra* and *Stichopus chloronotus* appear to be both locally abundant – as evidenced by relatively high CPUE – and widely distributed around the island's reefs.

Minimum harvestable lengths

Table 2 shows mean *in situ* lengths of commercially valuable species for which at least three individuals, and upwards of 134 individuals, were measured. The upper and lower 95% confidence intervals indicate the range of lengths over which we can be most confident the true mean length of the entire population of a species occurs.

Table 2. Mean *in situ* lengths, pooled across sites, of commercially valuable holothuroids. *n* = sample size; C.I. = confidence interval of mean. Lengths in centimeters.

Species	*n*	Mean Length	Lower 95% C.I.	Upper 95% C.I.
Actinopyga sp nov	65	10.2	10.2	10.2
Actinopyga varians	3	26.3	26.0	26.6
Bohadschia argus	74	31.9	31.7	32.1
Bohadschia bivittata	68	24.6	24.5	24.7
Bohadschia marmorata	9	19.2	19.1	19.3
Holothuria (*Halodeima*) *atra*	84	13.7	13.5	13.9
Holothuria (*Halodeima*) *edulis*	134	19.5	19.4	19.6
Holothuria (*Microthele*) *fuscogilva*	3	36.5	36.4	36.6
Holothuria (*Metriatyla*) *scabra*	3	20.0	19.6	20.4
Holothuria (*Microthele*) *whitmaei*	28	29.2	28.8	29.6
Pearsonothuria graeffei	8	36.8	36.3	37.3
Stichopus chloronotus	108	19.6	19.4	19.8
Stichopus horrens	3	23.0	20.7	25.3
Stichopus vastus	18	23.2	22.9	23.5
Thelenota ananas	23	54.5	54.2	54.8

Biodiversity inventory

A total of 66 provisional taxonomic units attributable to species have now been identified from Yap's waters: 33 holothuroids, 14 echinoids, 14 asteroids and 5 crinoids (Appendix 1). For comparison, Appendix 1 also includes a checklist of the two previous surveys known to us and which found several species not collected in the present survey. The high

Figure 3. Undescribed species of holothuroids found on Yap. A) *Opheodesoma* sp. B) *Holothuria* (*Semperothuria*) sp. *non flavomaculata*. C) *Holothuria* sp. *non gracilis*. D) *Actinopyga* sp.

number of holothuroids is probably due to an outsized collection effort for these species on our part, rather than a true representation of their proportional richness in the island's echinoderm fauna.

At least four (12%) of the holothuroids are in all probability new to science and formally undescribed (Figure 3): *Actinopyga* sp. (Figure 3D) is a small (about 12 cm undisturbed length) light to deep brown animal often with black transverse stripes that is found in high abundance in some seagrass beds. *Holothuria* (*Semperothuria*) sp. *non flavomaculata* (Figure 3B) is also found in seagrass beds in high abundance and is distinguished by its widely scattered and large, conical rose-coloured dorsal papillae. *Holothuria* sp. *non gracilis* (Figure 3C) is a nocturnal species found in crevices at the base of coral in deeper calm water of the blue holes around the island; it is grey to greenish grey and papillate dorsally with a dirty yellow ventrum. Another likely new species is one provisionally placed in *Opheodesoma*; it was found once at night in branching coral and has longitudinal white and red stripes (Figure 3A).

DISCUSSION

Prospects for a Sustainable Beche-de-mer Fishery

Yap has an abundance of commercially valuable species of holothuroids. We (and others previously, notably E. Tardy in an unpublished report by the South Pacific Commission, New Caledonia) observed populations of some of the most desirable commercial species, occurring at all of the sites we visited around the island. While most of these species do not appear to occur at the high population densities sometimes seen elsewhere in Micronesia, they, nevertheless, constitute an important and valuable resource for the island.

Conversations with stakeholders have made it clear that Yap is currently being targeted by at least three foreign buyers of beche-de-mer. Local fishers are paid for fresh, unprocessed holothuroids by a Yap-based intermediary, who processes the animals into the dried product, which is then sold to the foreign buyers, who ship the beche-de-mer to Asian markets, including Korea, China and the United States. At least one local processor has expressed a wish to reduce the number of foreign buyers (presumably to the buyer that they alone supply!). We suggest, however, that market competition among foreign buyers for Yapese product would appear to be beneficial for the price received by the local fishers and thus encouraged (should a legal fishery continue in a sustainable manner). A more detailed market analysis is required to ensure what strategy Yap should adopt when licensing foreign buyers of beche-de-mer.

Yap was also targeted by buyers in 1995 (Richmond 1996). The result, commendably, was to quickly respond by closing the fishery. Yap is now once again one of many areas that are being heavily targeted by the beche-de-mer industry, whose ships now ply tropical and temperate waters worldwide. The increasing demand for beche-de-mer (and other products, such as shark fin and live reef fish) is fueled in large part by the rapidly expanding cash economies in Asia. Global trade in beche-de-mer is a multimillion dollar industry and profits are high enough, and the industry largely unregulated, that the practice of a "boom and bust" fishery has become commonplace. Quality product (e.g., white teat fish) in Hong Kong markets can retail for over US$100 per kilogram. Exporters *preferentially* move into countries where regulation is non-existent and offer low prices for a resource that is easily harvested and is often not being used otherwise. Because of the cost of, and lag in developing, legislating and implementing a management plan, as well as the difficulty of enforcement and education, the local fishery often collapses before the management plan, if one is put in place at all, can take effect. Exporters know this and exploit this.

Foreign buyers are fully aware that regulations take time to implement and thus, they specifically target small, often young, cash-strapped nations, because there, profits are highest. Buyers often work "under the radar" of the government by enlisting local intermediaries who encourage collecting and transit of product for export. Foreign buyers often speak in terms of sustainability, such as performing a "demonstration fishery" or an "experimental fishery;" they also speak of the viability of "reseeding," "aquaculture," etc. to create an impression that this is the beginning of a long-term relationship. However, and most tellingly, they make *no* commitment, *no* monetary investment to such endeavors, and *no* data are ever methodically collected during the "experiments," much less analysed or made available in published form, or otherwise, to stakeholders. Alas, the goal of foreign exporters is always the same: obtain as much high-quality product in as short a time as possible and absent any consideration of the sustainability of the fishery, and then move on to the next naive fishery. The list of countries lured into this boom-and-bust practice is both long and growing: Fiji, Solomon Islands, Kosrae, Cook Islands, Galapagos Islands, Egypt, …. Given this sad history of repeated over-exploitation, the prospects for Yap's beche-de-mer fishery at first glance seem grim indeed.

Still, despite the generally cheerless prospects for beche-de-mer fisheries worldwide, there are solid reasons for hope with Yap. First, there *are* indeed examples of sustainable, long-term fisheries involving beche-de-mer, including those in California (USA), Newfoundland (Canada), Queensland (Australia) and elsewhere. Moreover, Richmond (1996) has pointed out that Yap brings several distinctive strengths to the table: 1) A leadership that has long valued marine resources for their cultural as well as economic value. 2) The traditional nature of fisheries knowledge in Micronesia. 3) The system of reef tenure that permits management at the village level.

It is not surprising therefore that in response to the accelerating pace of trade in beche-de-mer and its importance to the local economy, the Yap State legislature has introduced a referendum on the need for a management strategy, so as to ensure the long-term success of the fishery. This is a commendable measure and an initial step in avoiding the fate of fisheries in numerous other Pacific-island nations. In the section

Recommendations that follows, we submit our suggestions to begin managing Yap's beche-de-mer.

For further recommendations on the issue, we highly recommend the detailed report from a workshop that brought together considerable Micronesian-based expertise in the form of fisheries scientists, economists and governmental marine-resource officers: *Suggestions for the Management of Sea Cucumber Resources in Micronesia* (Richmond 1996). This report makes numerous helpful recommendations concerning the management of beche-de-mer fisheries in Micronesia. It has sections covering the biology of holothuroids as they relate to fisheries, management strategies, economic analyses and recommendations for a Micronesian-wide plan to develop beche-de-mer fisheries. To receive a free copy via post, email the senior author of this report, A. Kerr, at uogmarinelab@gmail.com. An electronic copy in pdf format (1.5Mb) is also available upon request. Another font of advice and information on beche de mer is available at the website of the South Pacific Commission, http://www.spc.int. Here, on their Coastal Fisheries pages, is a wealth of contact information with fisheries scientists and publications about the latest information on beche de mer, including the long-running publication, *The Beche-De-Mer Bulletin*.

Yap's Diverse Echinoderm Fauna

Yap now has 66 species of echinoderms recorded from its waters, including 33 species of holothuroids. These counts are likely large underestimates. By comparison, 202 species of echinoderms and 47 holothuroids are known from the much better sampled coasts of Guam

(Paulay 2003). Palau, because of its much larger areal extent of reefs and increased proximity to the global epicentre of marine diversity, likely has even more. Therefore we estimate that Yap will eventually reveal well over 100 species of echinoderms and over 40 holothuroids.

Yet, the most interesting results from the survey were the new species discovered, all of them holothuroids. At least four species encountered appear to be unknown to science. None appear to be restricted to Yap. While uncommon enough to have long avoided formal taxonomic treatment, these species have nevertheless been observed at other localities in the tropical western Pacific by us and others (Kerr et al. 2006; G. Paulay, personal communication; E. Tardy, personal communication).

For example, *Actinopyga* sp. (Figure 3D) was first observed in Yap in 1977, when the University of Guam Marine Laboratory surveyed the grassflats adjacent to Tomil Channel. The species was pictured and discussed in a technical report (Amesbury et al. 1978), although it was incorrectly identified as *Actinopyga echinites*. A specimen was collected and is now curated at the Royal Belgian Institute of Natural Science. The species has since been collected elsewhere, from Palau (G. Paulay, personal communication) and New Guinea (F.W.E. Rowe, personal communication). Neither we nor our colleagues have seen it elsewhere in the tropical Indo-west Pacific province, suggesting that it has a rather restricted geographic distribution. Its local distribution in Yap appears likewise patchy. It is restricted to the seagrass flats of the inner reef at a few localities around the island. We have seen it at the southern end of Tomil, where it occurs at surprisingly high population densities.

Actinopyga sp. is also reported from Waayan in Gagil (M. Hasurmai, personal communication).

Another undescribed species, with the provisional moniker *Holothuria* sp. *non gracilis*. (Figure 3C), was has also been seen in the Philippines (Kerr et al. 2006). It is one of the dominant echinoderms in the blue holes around the island in terms of both size and abundance. As in the Philippines, it is nocturnal lives below fair-weather wave base in crevices at the base of live coral. An unusual variant of presumably this species was also seen. While nearly all specimens in Yap were grey dorsally, two specimens were collected that were slightly smaller and distinctly olive. Further these specimens differed in that their unexpanded Cuvierian tubules, instead of being yellow as with the grey animals, were orange. See Figure 3 for images of some other new species of holothuroids.

Some species seen, while known to science, appeared to be unusual morphs seldom or not seen elsewhere in the Indo-Pacific. For example, *Bohadschia argus* usually possesses a light tan or grey to black ground colour. In Yap, it was sometimes completely white. Similarly, the echinoid (sea urchin) *Mespilia globulus*, a relatively common species throughout its large geographic range, usually has light coloured spines and white-tipped tubefeet. In Yap, the spines and tubefeet are jet black, a striking contrast to its smooth Yale-blue adambulacral regions. Several other species of echinoderms also exhibited unusual colour variations.

Yap also counts amongst its echinoderms one of the most beautiful of coral-reef invertebrates, the holothuroid *Thelenota rubralineata* (Figure 4). This species has been seen on deep forereef slopes of at least 60 m (B.

Figure 4. *Thelenota rubralineata*, the candy-cane sea cucumber, one of the most spectacular species of tropical holothuroids, recorded from deeper reefs on Yap (B. Greene, personal communication; photo copyright: D. Segar and E. Segar, www.reefimages.com)

Greene, personal communication). It has also been seen on other islands of Yap State, most recently in Ulithi from less than 30 m (V. Fread, personal communication).

In sum, Yap's biodiversity is both rich and under-explored. The most comprehensive treatment of Yap's biodiversity is of its terrestrial flora (Falanruw 2005). The present survey indicates that Yap's marine fauna is of similar uniqueness and scientific merit. Other groups of marine organisms on Yap will undoubtedly reveal a comparable number of interesting discoveries, many of them species new to science.

RECOMMENDATIONS

We make some initial recommendations for starting a beche-de-mer management plan on Yap. The following approach constitutes only one of several possible starting points.

Institute a moratorium on fishing until a management plan is in place. We understand that a referendum on this issue is before the legislature. Note that a moratorium of fixed period is more likely to be violated towards the end of its duration, as poachers and buyers may stockpile product in anticipation of the reinstatement of harvesting. Enforcement at such time should be especially vigilant.

Conduct an inventory of the island's commercially valuable species. We have performed a preliminary inventory and have taught methods for continuing the surveys to Marine Resources personnel. An inventory of unharvested (in fisheries parlance, "virgin") stocks provides baseline data to assess the status of the fishery and to estimate the minimum harvestable length (see below). We suggest a quick method for the initial inventory: record the lengths of all commercially exploitable species in timed swims of about an hour per person. This provides two valuable pieces of information: 1) population data on animal size used for calculating minimum harvestable length and 2) an estimate of an important quantity in fisheries management, the catch per unit effort, i.e., how much effort must be expended to harvest a given amount of beche de mer. While a centrally conducted inventory by the government may be desirable, it may also be preferable to ensure that each village performs their own inventory.

Institute island-wide minimum harvestable lengths for each species. Using minimum size is only of one many options for regulating harvesting (See Amesbury 1996 for other techniques). Minimum length, though, is the simplest measure to implement in the absence of more detailed information on biology and is also the simplest to enforce. The minimum harvestable size of a stock can be roughly calculated for most holothuroids as the average length of a species *before* harvesting has begun. This ensures that close to 50% of the reproductive capacity (50% of all eggs produced) is preserved. For a virgin stock, one not having previously experienced harvesting, this approach to management quickly results in a "fish down," an initial period of large catches of large animals. After this period, catch per unit effort drops considerably as fishers must wait for smaller animals to grow to harvestable size.

Institute MPAs or temporary closures to increase stock size and value. MPAs (marine protected areas) are an additional method by which to preserve the reproductive capacity of a stock. Additionally, "spill over" of animals to areas outside the MPA allows more and larger animals to be harvested. We have been told that at least three MPAs are now established on Yap, primarily along the eastern side of Maap. Regulating harvesting by instituting a minimum harvestable size rapidly removes the largest and most valuable stock from the reefs. However, the value of beche de mer rapidly plummets with decreasing product size. Hence, to more quickly grow out the remaining animals to the most valuable lengths, may require seasonal or rotating closures of areas to harvesting. The length of closure will depend on trade offs between economic concerns (e.g., maintaining catch per unit effort) and the growth rates of individual species. Closures might, for example, coincide with the onset of spawning to permit stocks to preserve population size. Determining when spawning occurs can be done as suggested in Richmond, Hopper and Martinez (1996). When closing the reefs to permit regrowth to harvestable size, periodic monitoring of length via timed swims should be performed to learn when reefs can be reopened.

Regulate harvesting and export at the level of local processors. On Yap, fishers sell their catches of fresh animals to, at present, at least three local processors of the final product for sale and shipment to foreign buyers. We recommend mandatory (i.e., legislated) reporting of harvests and percentages of undersized product. The intermediaries' dried product can be periodically assessed for lengths and amounts. Lengths will differ from the minimum harvestable lengths mentioned above, because the animal shrinks considerably with processing. Therefore, it will be necessary to know the relationship between minimum harvestable length and its processed length. This in turn requires information for each species on both these lengths for at least 30 or so animals. Then, the relation is determined via the best-fit regression line through the data as shown in Figure 5.

Continually assess the effectiveness of the management plan and modify it when necessary. A management plan, especially after it is first implemented, will likely require some fine tuning or, even, a major retool. As more data from monitoring of both stocks and exports collects, it may become clear that modification to harvesting regulations is needed to maintain the goal of the fishery (e.g., continue a reasonable catch per unit effort or level of income). For example, average length is only a very

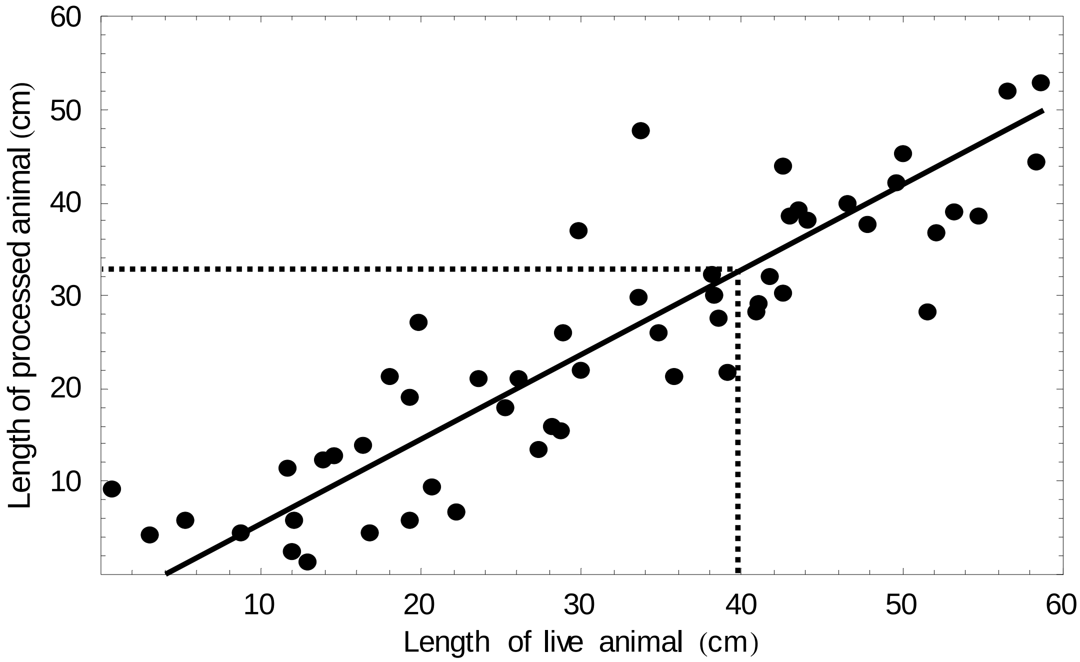

Figure 5. Calculating the minimum legal length of processed beche de mer from the minimum harvestable length of live animals. The points represent the live and dried lengths measured for 30 or more individual holothuroids. The solid line is the best-fit regression line through these points (as implemented in, say, *Microsoft Office Excel*). The dotted lines show how the minimum processed length is related to minimum harvestable length (40 cm in this example). This calculation must be done for each species.

rough guide to estimating 50% reproductive capacity. In fact, average length will usually underestimate 50% reproductive capacity somewhat in most situations. Still, given the biology of holothuroids, it is a reasonable starting point for a beginning fishery. A more refined approach measures gonad weight of females and calculates a minimum length based on reproductive maturity of females. This analysis might suggest that a larger (or smaller) minimum harvestable size is preferable. We also recommend that after a year or two that a fisheries scientist and a fisheries economist (e.g., from the South Pacific Commission or University of Guam) be invited to learn about Yap and its experiences, then have them examine the fisheries at length to suggest other possible refinements.

Uncertainties and potential problems. The above recommendations are made in the absence of much information usually needed to form a fisheries management plan. We, therefore, foresee several issues needing consideration:

1) The main unanswered question is how much money can be sustainably received by a fisher after the initial fish-down of virgin stocks? Will the density and growth rates of the holothuroids permit a continuous harvest, even at some low level, to sustain a trickle of cash into the local economy? These questions concern scale of sustainability and holothuroid life-history traits. The answers should become apparent with increasing data on the status of the fishery, such as interviews with, or surveys of, fishers and their satisfaction with catch size.

2) After fish-down, fishers may become dissatisfied with small catches and insist that management has been a failure. It is important that they understand, perhaps via stakeholder meetings, that ultimately, the amount of harvesting that is sustainable is determined not simply by even the best management, but by the number of fishers and how fast holothuroid reproduce and grow. Alas, tropical holothuroids both reproduce and grow rather slowly. They should be prepared well ahead of time for the possible need for temporary closures to allow stocks to recover.

3) Another important issue is what to do with undersized catch. Because enforcement must occur after processing, the local buyers must incur this risk. This has the beneficial effect them becoming an ally in enforcement at the level of the fisher. Nevertheless, even given these inducements, some portion of the processed product – potentially valuable – will be

undersized. Amesbury (1996) cautions against the temptation to sell undersized product, as it creates a demand for undersized product that will be met by fishers, effectively undermining the management plan.

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Appendix 1. Provisional Checklist of Shallow-water Echinoderms from Yap, Western Caroline Islands, Micronesia. The subheading "Tardy" indicates an unpublished report of a 2004 survey led by E. Tardy (South Pacific Commission, New Caledonia) for the Chief of Marine Resources, Yap State. "Clouse & Janies" refers to a collection made in 2002 by R. M. Clouse (Harvard University) and D. A. Janies (Ohio State University) and deposited in the American Museum of Natural History, New York (see also Clouse et al. 2005). The record for *Thelenota rubralineata* is based on an unpublished photo by B. Greene (University of Hawaii) from 64 m depth.

Species	Survey		
	This study	Tardy	Clouse & Janies
HOLOTHUROIDEA			
Actinopyga varians	X	X	
Actinopyga sp. "tiger stripes"	X	X	X
Bohadschia argus	X	X	X
Bohadschia bivittata	X	X	X
Bohadschia koellikeri	X		
Bohadschia marmorata	X		
Chiridota hawaiiensis			X
Holothuria (*Acanthotrapezia*) *coluber*	X	X	
Holothuria (*Cystipus*) *rigida*	X		
Holothuria (*Halodeima*) *atra*	X	X	
Holothuria (*Halodeima*) *edulis*	X	X	
Holothuria (*Mertensiothuria*) *hilla*	X		X
Holothuria (*Metriatyla*) *scabra*	X	X	
Holothuria (*Microthele*) *fuscogilva*	X		
Holothuria (*Microthele*) *fuscopunctata*		X	
Holothuria (*Microthele*) *whitmaei*	X	X	
Holothuria (*Platyperona*) *excellens*	X		
H. (*Semperoth.*) sp. *non flavomaculata*	X	X	X
Holothuria (*Thymiosycia*) *impatiens*		X	X
Holothuria (*Theelothuria*) *turriscelsa*	X		
Holothuria sp. *non impatiens*	X		
Holothuria sp. *non gracilis*	X		
Opheodesoma sp. "olive and white"	X		
Opheodesoma sp. "red stripes"	X		
Opheodesoma sp. "green in seagrass"	X		

Appendix 1. Continued.

Species	Survey		
	This study	Tardy	Clouse & Janies
HOLOTHUROIDEA			
Pearsonothuria graeffei	X	X	
Polyplectana galatheae	X		
Stichopus chloronotus	X	X	
Stichopus horrens	X	X	
Stichopus vastus	X	X	
Synapta maculata	X		
Thelenota ananas	X	X	
Thelenota rubralineata	X		
ECHINOIDEA			
Clypeaster reticulates	X		
Diadema savignyi	X		
Echinometra mathaei	X	X	
Echinometra sp. “dark”	X		
Echinometra sp. A	X		
Echinostrephus aciculatus	X		
Echinothrix calamaris	X		
Echinothrix diadema	X		
Eucidaris metularia	X		
Heterocentrotus trigonarius	X		
Mespilia globosa	X		
Metalia sp.	X		
Pseudoboletia maculata	X		
Tripneustes gratilla	X	X	
ASTEROIDEA			
Acanthaster planci	X		
Asterinidae sp.	X		
Coriaster granulatus	X		
Culcita novaeguineae	X		
Echinaster callosus	X		
Echinaster luzonicus	X		
Fromia nodosa	X		
Fromia sp.	X		
Leiaster leachii	X		

Appendix 1. Continued.

Species	Survey		
	This study	Tardy	Clouse & Janies
Linckia guildingii	X		
Linckia laevigata	X		
Linckia multifora	X		
Mithrodia clavigera	X		
Protoreaster nodosus	X		
OPHIUROIDEA			
Amphiura sp.	X		
Ophiocoma erinaceus	X		
Ophiocoma scolopendrina	X		
Ophiocoma sp. *non erinaceus et non scolopendrina*	X		
Ophiomastix janualis	X		
Ophiomastix caryophyllata	X		
Ophiarachna incrassata	X		
Ophiuroidea sp. “smooth, brown arm bands”	X		
Ophiactis savignyi	X		
CRINOIDEA			
Comaster schlegelii	X		
Crinoid sp. 1 “small, white, few pinnae”	X		
Phanogenia sp. “with cirri”	X		
Mariametridae sp. 1	X		
Mariametridae sp. 2	X		

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