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Distribution, Abundance and Management of Potential Commercial Holothurians in Pohnpei Lagoon, Federated States of Micronesia

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Abstract—From May 28 to June 5, 2004, sixty-three 400-m^2 stations were surveyed throughout the five municipality lagoon waters of Pohnpei Island to evaluate the densities and distribution of potential commercial holothurians. Thirty-eight per cent of the stations were concentrated on the barrier-reef crest, 36.5%, on the back barrier reef platform, and 25.5% within the patch reefs/seaward portion of the fringing reef flat complex. A total of 12,806 individuals represented by six species were registered, equivalent to a mean density of 0.51 ind.m^{-2}. *Holothuria atra* composed 87.1% of the total number, followed by *Stichopus chloronotus,* with 5.0%, *Actinopyga mauritiana,* 4.5%, *Holothuria edulis,* 2.9%, *Bohadschia* sp., 0.4%, and *Holothuria whitmaei,* 0.1%, respectively. By municipalities, all species confound, Uh recorded the highest densities with 0.83 ind.m^{-2}, the lowest being Sokehs with 0.18 ind.m^{-2}. By physiographic zone, a contagious distribution is observed, *H. edulis* being concentrated within the fringing/patch reef complex, while *A. mauritiana* occurs mainly on the barrier-reef crest, most frequently at Nett, constituting 25.6% of the 1,958 individuals surveyed there. *S. chloronotus* and *H. atra* have representatives in all three defined physiographic zones. The estimated standing crops are 15,000 mt for *H. atra,* a little over 900 mt for *H. edulis,* 339 mt and 244 mt, respectively, for *S. chloronotus* and *A. mauritiana.* Comparison between annual harvest potential, market prices and mean exploitable age permits one to estimate the gross revenue of a given species. Due to forecasted high annual harvest volumes, *H. atra* offers the best commercial potential. *S. chloronotus* and *A. mauritiana,* are commercially attractive mainly because of their relatively high commercial value. Management strategies are suggested and should be adopted before any commercial holothurian fishery is implemented.

Introduction

There has been a marked increase in demand and value for beche-de-mer (dried, processed sea cucumber) from the southeast Asian markets since the early

1980s. The demand is associated with drops in supplies from major producing countries, along with rapidly expanding levels of imports into mainland China (Preston 1989, Kinch 2002, Chen 2003). These trends have initiated a major increase of new producer countries, largely from the Pacific basin and a shift in the species being exploited from the highly valued species to moderately and low valued species (Preston 1993, Conand & Byrne 1993, Conand 2001, Bruckner et al. 2003).

Sea-cucumber fisheries are now expanding into Micronesia, where around seventeen species of commercial value have been identified (Richmond 1996, 1999). In the Federated States of Micronesia (FSM), holothurian, like other inshore fishery resources, remain mainly exploited for subsistence and the local market (Smith 1992, Callaghan 1996). But, in the 1990s, small-scale commercial sea-cucumber fisheries have been initiated in Yap (Richmond 1999, Lambeth 2000), Kosrae (Lindsay & Abraham 2004) and in Pohnpei (M. Abraham, pers. comm. 2004). In all three cases, concern over the state of these unregulated resources has triggered government authorities to impose a ban on harvesting until baseline surveys and stock assessments are performed (Richmond 1999, Lambeth 2001, Linsay & Abraham 2004, M. Abraham, pers. comm. 2004). Previous marine resource surveys available for the FSM are mainly qualitative or at best semi-quantitative (Amesbury et al. 1977, Retherford 1978, Grosenbaugh 1978, 1981, Eldredge et al. 1979, Birkeland 1980, Moore 1986, U.S. Army Corps of Engineers 1986, 1989a, 1989b, Holthus 1987). More recently, quantitative data on holothurian abundance were compiled for Kosrae, Chuuk, and Pohnpei (Kerr 1994, Richmond 1996, Edward 1997, Lindsay & Abraham 2004).

In Pohnpei State, there is a growing interest from foreign investors for the holothurian stocks. This could represent an alternative way to diversify the state's coastal fisheries. Following a request from the Economic Development Authority (EDA), a survey has been initiated to assess the distribution and abundance of holothurians in the shallow waters of Pohnpei island lagoon. Personnel of the College of Micronesia, National Campus, were approached to collaborate with fieldwork and to guide the fisheries division of EDA on formulating a sensible management program.

The objective of the present paper is twofold: 1) to evaluate the densities, distribution and standing crops of selected holothurian species, and; 2) to use this information as a basis in formulating a resource management and monitoring program for a sustainable commercial holothurian fisheries at Pohnpei.

Materials and Methods

STUDY AREA

Pohnpei Island (6º50'N, 158º10'E) is the largest land mass (365 km^2) in the Federated States of Micronesia (FSM), located slightly north of the equator in the western Pacific Ocean (Fig. 1). Roughly pentagonal in shape with a diameter of about 23 km, Pohnpei proper is a mountainous volcanic island, reaching 791 m

(Bascom 1946, Laird 1982). The 35,000 inhabitants live along the narrow belt of level land around the shore (FSM 2002). Mean annual rainfall at sea level is about 482 cm (Laird 1982) and the precipitation supports lush vegetation in the interior and feeds forty or so streams and tributaries, which drain into nearshore lagoonal waters. An extensive fringing reef covered with seagrass beds and a well-developed mangrove forest skirts the main island.

The lagoon itself encircles most of Pohnpei Island, except along the southeast side where the fringing reef extends into a platform leading directly to the open ocean (Fig. 1). The lagoon has numerous patch reefs and contains a system of channels reaching to 90 m depth (Ashby 2003). In the northern lagoon there is a group of reef-fringed basaltic islands.

An extensive barrier reef about 3 km offshore (U.S. Army Corps of Engineers 1986), supports a few sand islets, and over fifteen deep passes (Holthus 1987).

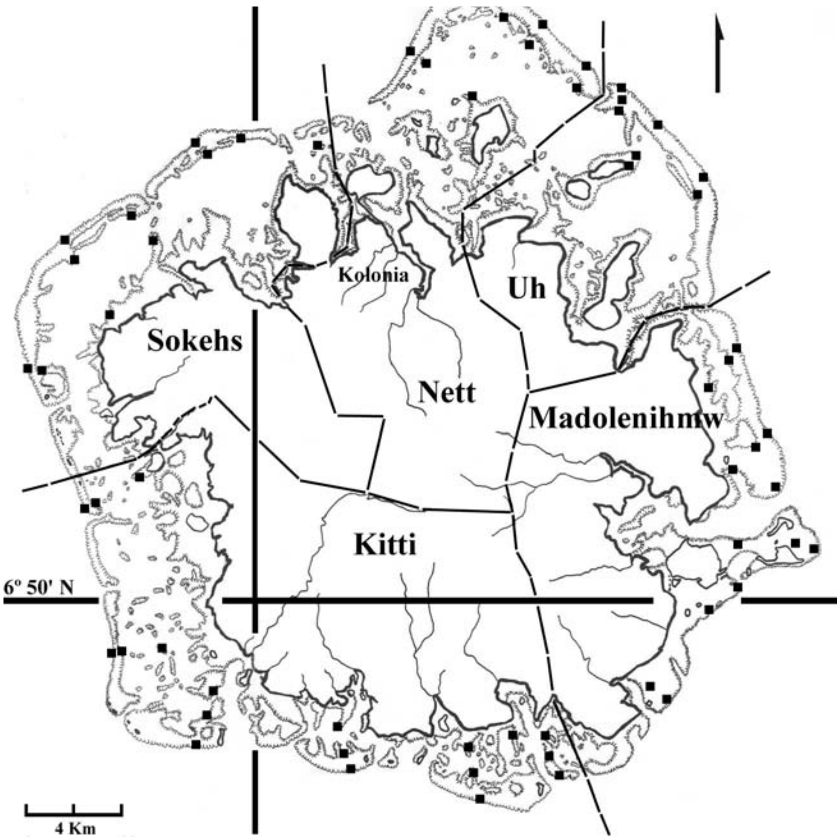

Figure 1. Map of Pohnpei showing the location of the sampling sites (black squares) in the five municipalities: Nett, Uh, Madolenihmw, Kitti, Sokehs.

FIELD SURVEY

Pohnpei island lagoon was subdivided according to municipality: Madolenihmw, Nett, Kitti, Sokehs, and Uh (Fig. 1). Between May 28 and June 5, 2004, a group of seven people divided into three teams sampled a total of 63 stations: 15 stations in Madolenihmw, 10 in Nett, 19 in Kitti, 11 in Sokehs, and 8 in Uh. The holothurian count at each station is based on a set of four parallel 50-meter long by 2-meter wide (100 m^2) transects distanced five meters apart, for a total area of 400 m^2 per station. All transects were oriented at right angles to the outer reef margin. In each municipality, sampling stations were set haphazardly within three physiographic zones at less than 5 m depth: (1) The seaward portion of the fringing reef flat and the lagoon patch reefs of calcareous sand, rubble deposits and scattered live coral heads (U.S. Army Corps of Engineers 1986). (2) The back reef terrace of the barrier reef, dominated by sand and rubble deposits with live coral heads forming microatolls, and usually sloping into extensive sand deposits in deeper waters (U.S. Army Corps of Engineers 1986). (3) The crest of the barrier reef, a solid reef rock pavement covered with scattered boulders and shingles of dead corals (U.S. Army Corps of Engineers 1986).

The nearshore portion of the fringing reef with its associated seagrass beds, the lagoon slopes, the channels, the passes and the seaward barrier reef terrace and slope were not investigated. For each transect, holothurians encountered were recorded to species. We did not look in crevices, under coral heads or overturn rocks. Station locations were recorded by GPS when available, otherwise they were derived from compass bearings or triangulating from familiar landmarks.

STANDING CROP

The estimated population size of the four most abundant species surveyed was derived for each municipality by multiplying the mean density of each species by respective physiographic zone by the total area of the applicable habitat. These given surface areas are based on estimates obtained by subdividing into 64 grids of 125m × 125m (15,625 m^2) the 1000m × 1000m (1 km^2) grid topographic map of the Island of Pohnpei (scale 1:25,000) published by the United States Department of Interior (Map edited 1983: N654.5-E15823 North Half; N645-E15823 South Half). Within the barrier reef complex, it was impossible to distinguish the crest from the back reef. In the present study, the crest area was arbitrarily given coverage of 25% and the back reef, 75%. Within the fringing/patch reef physiographic zone, the extent of the seagrass meadows could not be distinguished from the rest of the zone. Thus, the standing crops in this zone is likely slightly over estimated

Since, the mean size (length or weight) composition of the respective populations was not evaluated in the present study, a necessary parameter needed to calculate the standing crop, mean individual wet weight for the given species were taken from Desurmont (2003).

Data Analysis

Two-way analysis of variance (ANOVA) with unequal sample size was applied to test for differences ($\alpha \leq 0.05$) in species abundance (for the four most common species and for all species pooled), among physiographic zones and municipalities, and for the interaction between these two independent factors (GLM-Minitab14). Significant differences detected in full model, were further analyzed using pairwise interactions (Tukey test) to separate those means that differed. To improve normality and equalize variances, a log10 (x+1) transformation was employed to the count data before using ANOVA procedures (Fowler & Cohen 1990).

Results

Table 1 summarizes the data by municipality, physiographic zone and species. A total of 12,806 sea cucumbers comprising six species were counted in a total sample area of 25,200 m^2, an equivalent of 0.51 ind.m^{-2}. The relative frequencies of the species are as follows: *Holothuria (Halodeima) atra* Jaeger accounting for 87.1% of the total holothurians surveyed, *Stichopus chloronotus* Brandt, 5.0%, *Actinopyga mauritiana* (Quoy & Gaimard), 4.5%, *Holothuria (Halodeima) edulis* Lesson, 2.9%, *Bohadschia* sp., 0.4%, and *Holothuria (Microthele) whitmaei* Bell, formerly *Holothuria (Microthele) nobilis* (Selenka), 0.1%.

The station frequency (i.e. the number of stations where the sea cucumber species was observed in comparison to the total number of stations) is presented in Table 2. *Holothuria atra* is found in 73% of the stations, followed by *S. chloronotus,* in 66.7% of the sampled sites. The values rapidly dropping afterwards with *A. mauritiana* present in 28.6% of the stations, *H. edulis* and

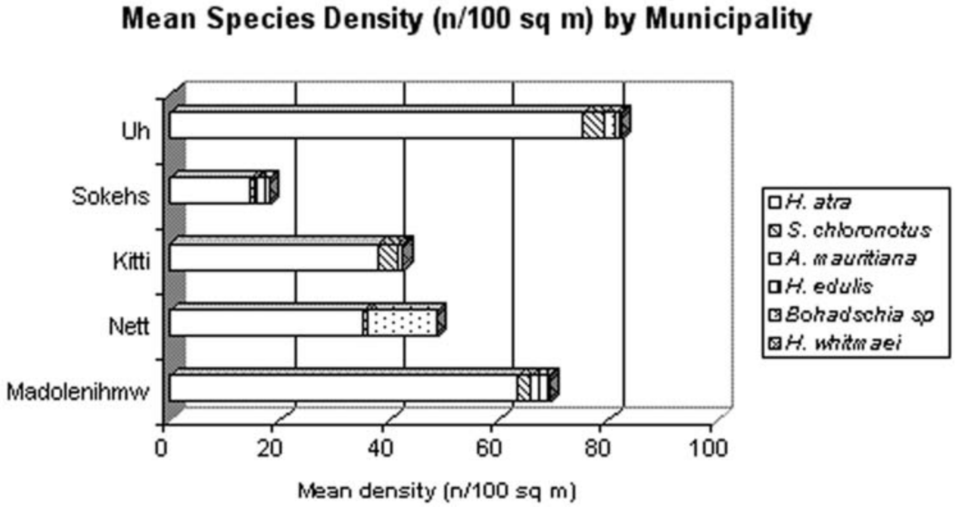

Figure 2. Total and mean species density (n/100 m2) by municipality.

Table 1. Compiled data by municipality, physiographic zone, and species. *(S. chlor–Stichopus chloronotus; A. mau–Actinopyga mauritiana; Boh. sp–Bohadschia* sp.; *H. whit–Holothuria whitmaei; H. atra–Holothuria atra; H. edulis–Holothuria edulis)*

Municipality	Physiographic Zone (# sites)	*S. chlor*	*A. mau*	*Boh. sp*	*H. whit*	*H. atra*	*H. edulis*	Total (No)	Total (%)
Madolenihmw	Crest (7)	40	9	3	0	885	0	937	
	BR Flat (5)	49	0	3	0	2,008	0	2,060	
	FR/Patch reef (3)	53	2	0	13	916	188	1,172	
	Total (15)	142	11	6	13	3,809	188	4,169	32.6%
Nett	Crest (6)	29	477	0	1	540	1	1,048	
	BR Flat (2)	8	27	0	0	213	0	248	
	FR/Patch reef (2)	2	0	0	0	653	7	662	
	Total (10)	39	504	0	1	1,406	8	1,958	15.3%
Kitti	Crest (6)	17	3	2	0	117	13	152	
	BR Flat (9)	181	0	21	2	2,296	25	2,525	
	FR/Patch reef (4)	85	0	0	0	470	8	563	
	Total (19)	283	3	23	2	2,883	46	3,240	25.3%
Sokehs	Crest (3)	22	6	0	0	13	0	41	
	BR Flat (4)	18	2	2	0	89	0	111	
	FR/Patch reef (4)	0	0	6	0	543	101	650	
	Total (11)	40	8	8	0	645	101	802	6.3%
Uh	Crest (2)	57	49	0	0	143	0	249	
	BR Flat (3)	60	6	6	0	867	0	939	
	FR/Patch reef (3)	14	1	4	0	1,402	28	1,449	
	Total (8)	131	56	10	0	2,412	28	2,637	20.6%
Is.Total	Crest (24)	165	544	5	1	1,698	14	2,427	19.0%
	BR Flat (23)	316	35	32	2	5,473	25	5,883	45.9%
	FR/Patch reef (16)	154	3	10	13	3,984	332	4,496	35.1%
Total (all sites)	63 sites	635	582	47	16	11,155	371	12,806	
	Density (no/site)	10.1	9.2	0.7	0.3	177.1	5.9	203.3	
	Density (no/100sq.m)	2.5	2.3	0.2	0.1	44.3	1.5	50.8	
	(percentage)	5.0%	4.5%	0.4%	0.1%	87.1%	2.9%		

Bohadschia sp., each around 20% of the total stations, and finally *H. whitmaei,* recorded in only three sites (4.8%) of the 63 stations.

The mean species density by municipality is presented in Figure 2. A two-way ANOVA reveals a significant difference ($F_{4, 48} = 4.11$, $p = 0.006$). Pairwise comparisons show at both Uh and Madolenihmw, the two highest absolute mean densities of 82.5/100 m^2 and 69.5/100 m^2, respectively, to be significantly different with the lowest recordings of 18.3/100 m^2 registered at Sokehs (Tukey test, Uh and Sokehs, $p = 0.037$, Madolenihmw and Sokehs, $p = 0.009$).

Species-wise, *H. atra,* is by far the most common holothurian in each of the municipalities, accounting for well over 80% of the total individuals, except in Nett, where it comprises only 72% of the total. Also at Nett, *A. mauritiana* composes 25.6% of the 1,958 individuals enumerated, corresponding to a total mean

Table 2. Station frequency for the six holothurian species enumerated in the survey. *(S. chlor–Stichopus chloronotus; A. mau – Actinopyga mauritiana; Boh. sp–Bohadschia* sp.; *H. whit–Holothuria whitmaei; H. atra –Holothuria atra; H. edulis–Holothuria edulis)*

	No of sites	*S.chlor*	*A.mau*	*Boh. sp*	*H.whit*	*H.atra*	*H.edulis*
Madolenihmw	15	10	5	3	1	15	2
Nett	10	6	6	0	1	8	2
Kitti	19	15	1	4	1	15	5
Sokehs	11	6	2	3	0	1	3
Uh	8	5	4	2	0	7	1
Total	63	42	18	12	3	46	13
Percentage		66.7%	28.6%	19.0%	4.8%	73.0%	20.6%

density of 13.0/100 m^2 in that municipality alone. There is no significant difference in the mean species density between municipalities for *S. chloronotus* (two-way ANOVA, $F_{4, 48} = 1.40$, $p = 0.248$), and *H. edulis* (two-way ANOVA, $F_{4,48} = 0.22$, $p = 0.929$). *H. atra* shows a significant difference (two-way ANOVA, $F_{4,48} = 3.30$, $p = 0.018$) linked to Madolenihmw and Sokehs (Tukey test, $p = 0.015$). While, *A. mauritiana* presents a significant difference (two-way ANOVA, $F_{4, 48} = 5.74$, $p = 0.001$), mainly due to the high mean densities recorded at Nett (Tukey test, Madolenihmw and Nett, $p = 0.022$, Sokehs and Nett, $p = 0.027$, Kitti and Nett, $p = 0.002$).

Figure 3 summarizes the total mean species density (individuals/100 m^2) by physiographic zone. An uneven distribution is observed. *H. edulis* is concentrated within the fringing/patch reef complex (two-way ANOVA, $F_{2, 48} = 7.74$, $p = 0.001$) while *A. mauritiana,* mainly aggregates on the crest of the barrier reef (two-way ANOVA, $F_{2, 48} = 12.15$, $p = 0.000$). Although *S. chloronotus* and *H. atra* are common in each physiographic zones, *H. atra* was significantly less abundant on the crest compared to the fringing/patch reef complex (two-way ANOVA, $F_{2, 48} = 5.34$, $p = 0.008$; Tukey test, crest and FR flat/patch reef, $p = 0.007$). No significant differences in mean densities were found between physiographic zones for *S. chloronotus* (two-way ANOVA, $F_{2, 48} = 0.16$, $p = 0.856$). The other species are too few in numbers to detect any distribution pattern. When all species are pooled, there is a significant difference in the total mean number of holothurians by physiographic zone (two-way ANOVA, $F_{2, 48} = 4.02$, $p = 0.024$). Pairwise comparisons show the difference to be linked between the lowest recordings registered at the crest (25.3/100m^2) and the highest, recorded at the fringing/patch reef complex (70.3/100m^2) (Tukey test, $p = 0.020$). Finally, the interaction between the physiographic zones and municipalities show significant differences uniquely for A. mauritiana (two-way ANOVA, $F_{8, 48} = 2.39$, $p = 0.030$).

Furthermore, the patchy distribution is evident when looking at the minimum, maximum and mean densities (individuals/100m^2) for each species (Table 3). There is marked difference in abundance between physiographic zones and even between sites within a same zone. At one site in the back barrier reef platform, *H. atra,* registers a maximum of 274/100m^2 (27,400 ind.ha^{-1}), a value 4.6 times greater than the overall mean value for that physiographic zone. *H. edulis,*

Table 3. Minimum, maximum, and mean density values (ind./100 m^2) by physiographic zones. *(S. chlor–Stichopus chloronotus; A. mau–Actinopyga mauritiana; Boh. sp–Bohadschia* sp.; *H. whit–Holothuria whitmaei; H. atra–Holothuria atra; H. edulis–Holothuria edulis.* BR-Barrier reef; FR-Fringing reef)

Physiographic Zone (# sites)	Density (ind./100 sq.m)	S. chlor	A. mau	Boh. sp	H. whit	H. atra	H. edulis
Crest (24)	Minimum	0	0	0	0	0	0
	Maximum	9	43	1	1	109	2
	Mean	1.7	5.7	0.1	0	17.7	0.1
BR Flat (23)	Minimum	0	0	0	0	0	0
	Maximum	23	7	3	1	274	6
	Mean	3.4	0.4	0.3	0	59.5	0.3
FR/Patch reef (16)	Minimum	0	0	0	0	4	0
	Maximum	15	1	1	3	185	46
	Mean	2.4	0	0.2	0.2	62.3	5.2

records a maximum of 46/100m^2 (4,600 ind.ha^{-1}) in the fringing/patch reef complex, almost nine fold the corresponding mean value. In turn, *A. mauritiana,* numbers up to 43/100m^2 (4,300 ind.ha^{-1}) on the barrier reef crest, while *S. chloronotus,* accounts for a maximum of 23/100m^2 (2,300 ind.ha^{-1}) on the back reef platform.

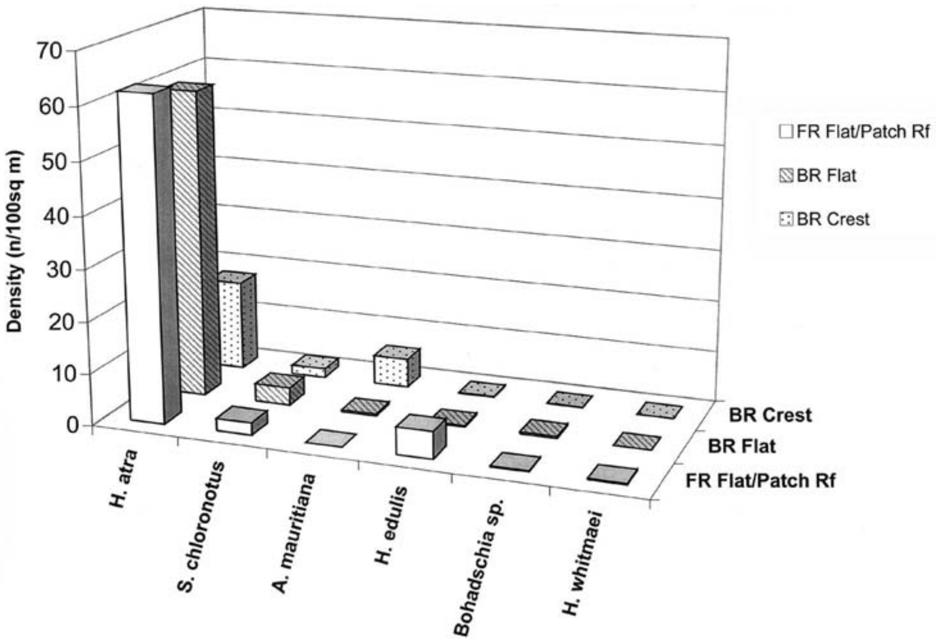

Figure 3. Mean species density (n/100 m^2) by physiographic zone. FR Flat/Patch Rf: Outer part of the fringing reef/patch reef complex; BR Flat: Back reef platform of the barrier reef; BR Crest: Barrier reef crest. The numbers on top of the columns represent the exact mean species density (n/100 m^2).

Table 4. Total surface area of Pohnpei lagoon in square kilometer (km^2) by physiographic zone and by municipality. (Rf-Reef)

		Lagoon						
	Barrier Reef (Crest/ Back Rf)	Deep zones (> 5 m)	Patch Rf (< 5 m)	Fringing Rf (< 5 m)	Silt zones (River/ Estuary)	Mangrove	Total without mangrove	Total with mangrove
Kitti	13.0	54.7	9.2	13.6	1.4	24.5	91.8	116.3
Sokehs	8.3	42.8	5.5	8.6	2.4	13.6	67.5	81.0
Nett	9.7	39.2	2.6	7.2	1.4	3.4	60.0	63.5
Uh	6.1	25.3	4.6	9.2	0.0	3.3	45.2	48.5
Madolenihmw	8.4	14.4	6.1	18	2.3	12.1	49.1	61.3
Total (sq km)	45.3	176.3	28.0	56.5	7.5	56.9	313.7	370.6

Estimates of the Standing Crop

Table 4 represents the total surface area of Pohnpei lagoon in square kilometers (km^2) by physiographic zones and by municipality.

Based on these respective surface areas, Table 5 shows the total mean number of individuals for the four most common species and their standing crop by municipality. *H. atra* has the highest standing crop with 15,000 mt, followed by H. edulis with a little over 900 mt. The other two species, *S. chloronotus* and *A. mauritiana,* are approximately 339 mt and 244 mt, respectively. These latter two species are of medium to high commercial value, while the former two are much less valued. By municipality, *A. mauritiana* is mostly found on the crest and back reef in Nett (218 mt), while *S. chloronotus* show the highest standing crops on the fringing/patch reef complex of both Kitti (121 mt) and Madolenihmw (107 mt). *H. atra* is common and distributed throughout the lagoon. Finally *H. edulis,* offers the highest potential in Madolenihmw, where nearly 756 mt is estimated on the fringing/patch reef area.

Discussion

Six sea cucumber species were enumerated during the present survey, all being of some commercial value. Smith (1992), in a report on marine resources profiles of the FSM, lists a total of twelve holothurian species of commercial or subsistence value for Pohnpei State alone, this number reaching seventeen when considering the other three States and genera groups. The relatively low species diversity reported here can be attributed to a number of reasons. First, the survey was restricted to shallow water (<5 m depth) which accounts for 56% (156.3 km^2) of the lagoon surface area. The uninvestigated deeper zones such as the reef slopes, channels and passes, hold deeper water species, such as the prickly red-

Table 5. The estimated population size and standing crop by municipality for the four most common species surveyed. The mean weight per individual (*) for the respective species is taken from Desurmont (2003). (Madol.-Madolenihmw; Is.-Island; Rf – Reef; Fr – Fringing)

			A. mauritiana			S. chloronotus			H. atra			H.edulis		
		Area (sq. km)	Mean densitiy (no/ 400sq.m)	Total no.	Total Biomass (0.3 kg/ ind)* (kg)	Mean densitiy (no/ 400sq.m)	Total No.	Total Biomass (0.1 kg/ ind)* (kg)	Mean densitiy (no/ 400sq.m)	Total No.	Total Biomass (0.2 kg/ ind)* (kg)	Mean densitiy (no/ 400sq.m)	Total No.	Total Biomass (0.2 kg/ ind)* (kg)
Kitti	Barrier Rf	13.0												
	Crest (25%)	3.3	0.5	4,063	1,219	2.8	22,750	2,275	19.5	158,438	31,688	2.2	17,875	3,575
	Back Rf (75%)	9.8	0	0	0	20.1	489,938	48,994	255.1	6,218,063	1,243,613	2.8	68,250	13,650
	Fr/Patch Rf	22.8	0	0	0	21.3	1,214,100	121,410	117.5	6,697,500	1,339,500	2	114,000	22,800
Sokehs	Barrier Rf	8.3												
	Crest (25%)	2.1	2	10,375	3,113	7.3	37,869	3,787	4.3	22,306	4,461	0	0	0
	Back Rf (75%)	6.2	0.5	7,781	2,334	4.5	70,031	7,003	22.3	347,044	69,409	0	0	0
	Fr/Patch Rf	14.1	0	0	0	0	0	0	135.8	4,786,950	957,390	25.3	891,825	178,365
Nett	Barrier Rf	9.7												
	Crest (25%)	2.4	79.5	481,969	144,591	4.8	29,100	2,910	90.0	545,625	109,125	0.2	1,213	243
	Back Rf (75%)	7.3	13.5	245,531	73,659	4.0	72,750	7,275	106.5	1,936,969	387,394	0	0	0
	Fr/Patch Rf	9.8	0	0	0	1.0	24,500	2,450	326.5	7,999,250	1,599,850	3.5	85,750	17,150
Uh	Barrier Rf	6.1												
	Crest (25%)	1.5	24.5	93,406	28,022	28.5	108,656	10,866	71.5	272,594	54,519	0	0	0
	Back Rf (75%)	4.6	2	22,875	6,863	20.0	228,750	22,875	289.0	3,305,438	661,088	0	0	0
	Fr/Patch Rf	13.8	0.3	10,350	3,105	4.7	162,150	16,215	467.3	16,121,850	3,224,370	9.3	320,850	64,170
Madol.	Barrier Rf	8.4												
	Crest (25%)	2.1	1.3	6,825	2,048	5.7	29,925	2,993	126.4	663,600	132,720	0	0	0
	Back Rf (75%)	6.3	0	0	0	9.8	154,350	15,435	401.6	6,325,200	1,265,040	0	0	0
	Fr/Patch Rf	24.1	0.7	42,175	12,653	17.7	1,066,425	106,643	305.3	18,394,325	3,678,865	62.7	3,777,675	755,535
Total Is.	Barrier Rf	45.3												
	Crest (25%)	11.3	22.7	642,694	192,808	6.9	195,356	19,536	70.8	2,004,525	400,905	0.6	16,988	3,398
	Back Rf (75%)	34.0	1.5	127,406	38,222	13.7	1,163,644	116,364	238.0	20,215,125	4,043,025	1.1	93,431	18,686
	Fr/Patch Rf	84.5	0.2	42,250	12,675	9.6	2,028,000	202,800	249.0	52,601,250	10,520,250	20.8	4,394,000	878,800
	Total			812,350	243,705		3,387,000	338,700		74,820,900	14,964,180		4,504,419	900,884

fish, *Thelenota ananas* (Jaeger), the amberfish, *T. anax* H.L. Clark, the leopardfish, *Bohadschia argus* Jaeger, and the black teatfish, *Holothuria (Microthele) whitmaei* (Conand & Chardy 1985, Cannon & Silver 1986). Second, within the shallow areas of the inner fringing reef complex, the extensive seagrass beds were not assessed. Finally, the more conspicuous epibenthic species were enumerated, while nocturnal active species, cryptic and burrowing forms were probably overlooked, such as *Holothuria (Thymiosycia) hilla* Lesson and *Holothuria (Mertensiothuria) leucospilota* (Brandt) (Hammond et al. 1985, Cannon & Silver 1986). In future surveys, all physiographic zones of the lagoon, including the seagrass beds and the deeper areas should be assessed.

A prevalent behavior pattern in aspidochirotes is increased nocturnal feeding (Hammond 1982, Preston 1993, Graham & Battaglene 2004). To account for species with nocturnal activity and those of cryptic nature, usually concealed during the day, night sampling should be undertaken as well, the results, being compared with the daytime findings.

A mean holothurian density of 0.51 ind.m^{-2} (5,100 ind.ha^{-1}) was estimated in Pohnpei from the total sampled surface area of 25,200 m^2. In Guam, Kerr et al. (1993) record a mean density of 1.82 ind.m^{-2} (18,217 ind.ha^{-1}) represented by nineteen species from a sampled space of 11,134 m^2 between depths of 0 to 23 m. On the reef flats of Kosrae, Kerr (1994) found a mean of 3.2 ind.m^{-2} (31,466 ind.ha^{-1}) from a total sampled area of 2,982 m^2. In comparison, Pohnpei records relatively low mean densities and species. Part of this difference is linked to the sampling approach. Although in all three studies, line transects were used as a quantitative tool, contrary to Pohnpei, in both Guam and Kosrae, within the sampling area, crevices were examined, rocks were turned over, and stands of macro-algae were searched through. Qualitative daytime and nighttime surveys were equally used permitting to augment the species composition. Ideally, comparisons between holothurian densities should be made in closely comparable habitats with the same sampling methodology and objectives, by the same investigators and expressed in the same unit areas (Bakus 1973, Conand & Chardy 1985).

By species, *Holothuria atra* clearly dominates, comprising 92% of the surveyed individuals in both Guam (Kerr et al. 1993) and Kosrae (Kerr 1994) and 87% in the present survey. Likewise, Tsuda (1997) in an estimate of sea cucumber populations of Saipan, found H. atra to be numerically dominant. *H. atra* is equally abundant in other parts of the western Pacific regions, as well. From an extensive survey in 2001 in Milne Bay province (Papua New Guinea), *H. atra* was the most abundant species, accounting for approximately half of all beche-de-mer stocks (Kinch 2002). In an elaborate study of the New Caledonian lagoon, Conand & Chardy (1985) found *H. atra* to be the most frequent representative (58% of the 216 stations) and the most abundant (34.9% of the total density). Studying holothuroid assemblages on coral reefs across the central section of the Great Barrier Reef, Hammond et al. (1985) observed that *H. atra* was by far the most abundant numbering 41% followed by *Stichopus choloronotus* with 35%. Corresponding observations are equally found in the Indian Ocean. For example, from a three-site survey on the fringing reefs of La Reunion Island, Conand & Mangion (2002) noted that *H. atra* dominated, representing 75% of the total sampled Holothuridea. According to Bakus (1973), *H. atra* may be the most common tropical sea cucumber. The wide distribution of this species throughout the Indo-Pacific is apparently due to it being a habitat generalist (Hammond et al. 1985).

For a given species, there are marked differences in densities within and between physiographic zones and municipalities. Such major variability in western Pacific sea cucumber abundances, have previously been compiled by Bakus (1973), Preston (1993), and Dalzell et al. (1996). Bruckner et al. (2003) underlines that in absence of fishing pressure, sea cucumbers may occur on Indo-Pacific reef flats at densities in excess of 35 ind.m^{-2} (350,000 ind.ha^{-1}). According to Preston (1993), marked abundance variability between geographic zones and localized patterns of distribution are common but reasons for these are not always clear. The topography of the reef, the degree of exposure and habitat type such as substratum type (sand or mud versus rocky biotopes), the amount of organic content in the sediment, the shelter available, and the interspecific competition, are all factors contributing to explain the regional patterns in distribution and abundance of a given species (Bakus 1973, Rowe & Doty 1977, Hammond et al. 1985, Preston 1993, Kerr et al. 1993, Long & Skewes 1997, Conand & Mangion 2002, Bruckner et al. 2003).

Species abundance by reef zonation is significantly (*A. mauritiana, H. atra,* and *H. edulis)* marked in Pohnpei lagoon. The overall mean density is observed to be the lowest in the crest area (.253 ind.m^{-2}) where the wave action is strongest, augmenting as one progressively goes inshore, with absolute mean values of .639 ind.m^{-2} in the back reef, and reaching .703 ind.m^{-2} in the fringing/patch reef area. Similar results of holothurians density distribution have been described for the lagoon of New Caledonia by Conand & Chardy (1985). They show that the density and biomass increased overall from the outer reef slopes to the crest, reaching the highest values on inner reef flats and in coastal areas.

Species themselves are also segregated according to their respective biological and ecological traits. *Actinopyga mauritiana* are commonly found in areas of strong waves and currents (Bakus 1973, Conand & Chardy 1985, Hammond et al. 1985, Preston 1993, Richmond 1999, Graham & Battaglene 2004, Lindsay & Abraham 2004). Having a well-developed flat clinging surface or trivium with numerous tube feet and a thick muscular body wall, this species is well adapted to high-energy zones (Kerr et al. 1993, Richmond 1996, 1999). Similarly, in the present survey, *A. mauritiana* is mainly confined to the crest of the barrier reef, the zone of highest exposure to incoming surge.

Although, *Holothuria atra* is equally found on the crest in considerable numbers, its densities augment markedly shoreward (Fig. 3). Kerr et al. (1993) equally found *H. atra* to dominate more inshore where wave action was slight. The same author notes that this species dominates in zones with smaller rubble and much sand. In the present study, specific sediment types were not recorded, but the general substrate description furnished from U.S. Army Corps of Engineers (1986) supports Kerr et al. (1993) observations. Long & Skewes (1997) also indicate *H. atra* to be significantly more abundant in shallow water with high cover of soft sediment and low cover of live coral. Though less abundant, *Stichopus chloronotus* shares the same physiographic zones as H. atra, also noted by Hammond et al. (1985). The predominance of *H. atra* and *S. chloronotus* on the reef flats, is a general characteristic of Indo-west Pacific reefs (Bakus 1973).

Densities of *H. edulis* were highest in the innermost part of the lagoon surveyed. This species was found to be relatively common in Pohnpei lagoon with an overall mean density of 148 ind.ha^{-1}, and reaching up to 4,700 ind.ha^{-1}. Amesbury et al. (1977) recorded in Yap lagoon mean densities fluctuating, depending on the habitat, between 200 and 1,500 ind.ha^{-1}. Curiously, this species was not recorded in Guam by Kerr et al. (1993), nor in Kosrae by Kerr (1994) and in Saipan, Tsuda (1997) observed only one individual. On Guam, *H. edulis* is more common in reef flats with finer terrigenous sediments (A. Kerr, pers. comm. 2004).

The total number and biomass estimates for the four most common species surveyed, furnishes a reasonable starting point in developing a resource management plan. Coupled with this information, monitoring of the harvest will permit estimates of remaining standing crop on the reef. As a rule of thumb, the annual harvest quota can be set at a value equal to the stock size divided by its average age within the exploitable size ranges (Amesbury 1996). For Pohnpei, there exist little to no information on holothurian growth, but that from other western Pacific regions can serve as a guide. Dalzell et al. (1996), in reviewing works of growth estimates, suggests that *S. chloronotus* and *A. mauritiana* have life spans of about five and twelve years, respectively. Assuming that the average age of individuals composing the exploitable size classes are three years for *S. chloronotus,* and seven years for *A. mauritiana,* then it becomes possible to use Amesbury (1996) formula to calculate quotas. This would mean that, one-seventh of the total exploitable biomass of *A. mauritiana,* and one-third for *S. chloronotus,* could be harvested on a yearly basis without depleting stocks. Applied to Pohnpei lagoon, this equals to 35 mt and 113 mt respectively. Further, assuming that both *H. atra* and *H. edulis* have a similar growth and age structure as *S. chloronotus,* then one-third of the total exploitable standing crop for these species, would correspond to nearly 5,000 mt and 300 mt, respectively. Considering an approximate 90% weight loss between the fresh weight to dried processed beche-de-mer (Conand 1979, Vuki & Viala 1990, Conand & Byrne 1993) and a minimum price of US$10.00/kg for both *A. mauritiana* and *S. chloronotus* and US$1.50/kg for both *H. atra* and *H. edulis* (INFOFISH Trade News, March 2002), then we estimate that Pohnpei lagoon could annually produce 3.5 mt (3,500 kg) of *A. mauritiana* trepang valued at US$35,000, 11.3 mt (11,300 kg) of *S. chloronotus* trepang valued at US$113,000, 500 mt (500,000 kg) of *H. atra* beche-de-mer valued at US$750,000, and 30 mt (30,000 kg) of H. edulis valued at US$45,000. In total, these species would represent an industry equivalent to nearly a million dollars in gross revenue.

From this analysis, we clearly show that despite low prices, the high volumes of H. atra render it a commercially attractive species. *S. chloronotus* is also promising, while *A. mauritiana* and *H. edulis,* because of its lower volumes for the former and low market price for the latter, appear to show limited potential. The beche-de-mer industry being labor intensive, harvesting and processing costs and expenses would be needed to evaluate economic feasibility such as the economic models suggested by Callaghan (1996).

Even though there is commercial potential for a sea cucumber fishery in Pohnpei, controls over the exploitation of the resource will be needed before any commercial harvest should be allowed. For example, in Saipan (Northern Mariana Islands), an initial commercial harvest targeting the surf redfish, *A. mauritiana,* and incidentally taking the black teatfish, *Holothuria (Microthele) whitmaei,* lasted only six-months (July 1996 through January 1997) before exploitation was halted. The harvest analysis from catch-effort statistics using three depletion models (Leslie, DeLury, and Akamine) indicated that 78 to 90% of the initial population sizes had been harvested from the management units (Trianni 2000).

According to Richmond (1996, 1999), resource surveys completed in other Micronesian areas, Palau, Guam, Saipan, and the FSM (Kosrae, Chuuk, Pohnpei), indicate that holothurian populations are recruitment limited so that natural stocks are easily overfished. For example, the author mentions that in Chuuk lagoon (FSM), the Japanese extensively exploited holothurian populations during the 1920's–1940's. Even though the resources were left to a standstill afterwards, over fifty years later, some populations have still not recovered and it is speculated that they will never recover unless resource enhancement is performed like reintroducing brooding stocks. But this issue still remains to be examined more thoroughly.

In many nations, the beche-de-mer fisheries develop rapidly, often reaching peak production within a few years and then rapidly decline or simply collapse afterwards (See Review in Bruckner et al. 2003). In most of these cases, baseline surveys were not initiated beforehand and without them, resource managers were unable to predict the sustainability of the fisheries. In the Federated States of Micronesia during the 1990s, government authorities had the courage to halt the newly established commercial trepang fishery, until scientific knowledge of the resource was acquired. Since this only represented a short-lived experimental fishery, exploitation had probably not peaked and the stocks still offer commercial potentials. Yet, Lindsay & Abraham (2004) in a survey initiated in Kosrae, shortly after commercial harvesting of sea cucumbers was banned in November 2000, recorded that the greenfish *(Stichopus chloronotus)* stocks were extremely low (0.015 ind.m^{-2} or 150 ind.ha^{-1}), apparently a direct result of commercial harvesting. Because of unfavorable weather conditions, *Actinopyga mauritiana,* the other species targeted in the survey was not assessed. But by comparing these post-harvest densities to pre-harvest densities from Kerr (1994), low densities of these commercially valuable holothurians existed prior to the start of the fisheries.

In Pohnpei, there now exists baseline information to guide the marine resources division in developing a management plan. The question now is: What are the plausible measures that can be undertaken to assure that the landings and fishing efforts are regularly monitored to prevent overexploitation?

Proposed Management Plan for Holothurian Fisheries in Pohnpei Lagoon

The management strategy suggested to the Pohnpei regulatory agencies (EDA and Marine Resources Division) favors a community-based approach reflecting the reef tenure system which still remains to a large degree influenced by the paramount chief of each municipality. The objectives targeted are foremost to prevent stock collapse, to assure long-term returns from the sea-cucumber fisheries, and to organize the fisheries in a way that there are social returns for each municipality.

To control the fishing effort, we suggest restricting the number of permits allocated by municipality and to restrict fishing practices to hand collecting and free diving. SCUBA gear, hookah systems and other techniques such as beche-de-mer "bombs" (see Crean 1977, Preston 1993, Dalzell et al. 1996, Bugitak & Lindsay 2004 for description) will be prohibited, thus enabling the protection of brood stocks in deeper waters. Respecting the no-take restrictions zones imposed by the Marine Protected Areas of Pohnpei lagoon is another way of protecting breeding stocks.

For each targeted species, a minimum size limit should be imposed. This size regulation for a given species will initially be in line with the knowledge on growth parameters reported in other parts of the western Pacific Islands and reviewed when corresponding biological data are available for Pohnpeian populations. Basic life history data are imperative in establishing sound resource management plans. Minimum size regulations not only benefit the reproductive capacity of the stock but also help to maximize profits, since the market prices of sea cucumbers depend on size categories, larger individuals being more valuable.

It is suggested to set up one landing point per municipality. Each of these five landing points will also serve as a processing center. In this manner, all sea cucumber landings will be centralized and consequently, management measures will be easier to monitor minimum size limits. At these centralized sites, standardized fishery statistics needed to make reliable stock assessments will be compiled for each fishing permit: harvest date, location and depth, fishing time, numbers and weights (volumes) collected by species. This information will permit to closely monitor the catch per unit effort (CPUE) (usually measured in numbers per man-hour). In turn, any significant decline in yield will be useful in deciding to halt harvest operations, if needed. Simultaneously, to closely follow the size-frequency distribution in time, length-weight measurements taken from samples of the respective harvested species will be compiled at regular time intervals. A drop in the mean individual size of a given population is a sign of harvesting pressure.

In parallel, to monitor any changes in beche-de-mer densities over time, periodic surveys will be conducted for use as an index of harvesting pressure (Amesbury & Kerr 1996). At the same time, size-frequency distribution of the surveyed species will estimate the proportion of pre-harvest individuals (juveniles) versus those that have attained the exploited size.

Since landing points will also serve as processing centers, it will be possible to regulate the harvested volumes in accordance to the processing capacity. This will prevent loss of harvested sea cucumbers due to spoilage before processing. Furthermore, centralized processing will permit to closely control and evaluate the production quality, a dominant factor in fixing the market price.

Trained personnel, such as a beche-de-mer liaison-officer from the Marine Resources Division, will initially help guide and supervise the community-based centers to assure that harvest records are systematically compiled and supervise the processing procedures and storage conditions to ensure a product of the utmost quality. Government authorities would provide training of these personnel, who will eventually overtake supervision of the operations.

Finally, the state authorities will be mandated to all marketing and export activities by licensing one or at the most, two exporters as suggested by Callighan (1996). All production will be marketed and sold in bulk. On the one hand, this should prevent lower prices often offered to independent primary producers, and on the other hand, this should attract more easily buyers because of higher volumes, and shipping and handling costs that will be proportionally reduced by economies of scale (Amesbury 1996). Also as mentioned by Callighan (1996), government intervention may be necessary to achieve a socially desirable distribution of the benefits.

This management approach integrates most of the management tools suggested by Richmond (1996, 1999) and Trianni (2000) and is in line with the fisheries management options and practices guideline recommendations recently adopted at the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Technical Workshop that occurred in Malaysia in March 2004 (Conand 2004). It will serve as a provisional management program and once additional information becomes available either at the resource level or at the economic level, management strategies will be updated accordingly.

A pre-harvest survey as the one on hand, furnishes the point of reference needed in order to set some of the necessary parameters to control harvest. But there still remains a lack of biological knowledge on the targeted species. Consequently, initiating a sea cucumber fishery should only be allowed at an experimental basis.

Of course this approach can only be successful if all participants whether the fishers themselves, the processors and the government authorities, are willing to work towards long-term sustainability of the resources rather than benefit from short-term financial gains, an approach that leads to a “boom and bust” cycle.

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