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Coral Reefs

The 1991–1992 rapid ecological assessment of Palau's coral reefs

J. E. Maragos[1], C. W. Cook Jr.[2]

[1] Program on Environment, East-West Center, 1777 East-West Road, Honolulu, HI 96848, USA
[2] The Nature Conservancy, Pacific Region, 1116 Smith Street, Suite 201, Honolulu, HI 96817, USA

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Abstract. At the request of the Palau and US governments, a team of 30 scientists under the leadership of the Nature Conservancy completed a rapid ecological assessment (REA) of nearshore marine resources in Palau in 1992. The REA provided ecological input to Palau's ongoing master plan for economic development and identified 45 marine sites worthy of special protection. The REA relied on previous literature, 1992 aerial photography, interviews, and field observations. A combination of qualitative and quantitative techniques were used to assess stony corals, other reef invertebrates, reef and shore fishes, macroscopic algae, seagrasses, sea turtles and other marine organisms. The REA covered a variety of coral reef habitats including beaches, seagrass beds, fringing reefs, lagoons, passes, channels, reef holes, patch and pinnacle reefs, barrier reefs, atolls, submerged reefs, mangroves, and "rock" islands. Major stresses to Palau's coral reefs include sedimentation from soil erosion, overfishing, and damage from periodic storms and waves. Minor stresses include dredge-and fill activities, sewage pollution, anchor damage, tourism use, ship groundings, aquarium fish collecting, and minor crown-of-thorns (*Acanthaster*) infestations.

Introduction

In October 1994, the Republic of Palau became an independent nation in free association with the United States. In anticipation of accelerated economic development, the Palau and US governments and the United Nations Development Program sponsored preparation of a national-level and a series of state-level master economic development plans. Earlier, the Palau government, with US financial assistance had requested a rapid ecological assessment (REA) of all ecosystems throughout the entire archipelago in 1992 to provide essential ecological and related environmental information for the master planning team and to identify and describe ecological areas worthy of special protection and conservation. The Nature Conservancy assumed leadership for accomplishing the REA with the assistance of scientists from several institutions from the region, including several volunteers. Unpublished synthesis reports completed in early 1994 present the results of the REA for the Southwest Islands (Maragos et al. 1994a) and for the main islands (Maragos et al. 1994b). This paper summarizes the findings of the entire REA. The full details of the REA are being published separately.

Carrespondence to: J. E. Maragos

Materials and methods

The REA involved the following steps:

- Meetings and interviews with Palau officials and government leaders
- Acquisition of high-resolution, low-altitude aerial photographs (in April and May 1992)
- Thorough literature review of all previous scientific investigations in Palau
- Interpretation and mapping of ecological areas using the aerial photographs and maps
- Interviews with knowledgeable or interested island residents, including the fishing community
- Field work including shoreline and underwater surveys
- Analysis and write up of technical reports
- Preparation and revision of the synthesis reports

The Palau REA was conceived in 1991 after considerable dialogue and discussion between the representive of The Nature Conservancy in Palau (C. W. Cook) and national government leaders in the Bureau of Resources and Development. In addition, state government officials from Tobi and Sonsorol requested advice on management of natural resources in the six Southwest Islands. A joint Palau government and Nature Conservancy proposal to conduct an REA for identifying candidate protected areas and other conservation measures was funded by the US Department of the Interior. This grant served as the principal catalyst in gaining the additional support of several other institutions and the volunteer participation of experienced coral reef scientists from the region. Grant funds were used to cover out-of-pocket expenses for travel, food, board and expenses associated with the field work, aerial photography, and preparation of published reports. Key Palauan officials were involved in every step and decision in the process outlined above.

Resource interviews were launched in advance in order to guide the limited field work to identify conservation problems and opportunities and to identify candidate study sites for evaluation as protected areas. Interviews were conducted with many Palauans during visits to Koror (Oreor) and eight outer village and island areas (Des Rochers and Matthews 1992). These interviews were crucial in: (1) explaining the purpose of the REA and gaining the necessary cooperation and support for field surveys, (2) describing sites where follow-up surveys were warranted, (3) describing past and present uses and controls over the harvest of coral reef resources, and (4) perceiving problems, conflicts, and opportunities regarding reef conservation.

Most field sites were selected on the basis of recommendations made from interviews, interpretation of aerial photographs, and review of the literature. Some sites were also selected while in the field. An effort was made to cover a broad cross section of different nearshore marine habitats and to investigate all areas identified by others as important or recommended for protection. Reef areas thought by interviewees to be stressed were also visited. In 1991 and 1992, all sandy beach areas in Palau were visited to assess sea turtle and sea bird nesting activity.

Approximately 30 researchers participated in one or more of the four field expeditions for the REA. The first expedition in June 1991, covered the coral reefs and large embayment of Negeremeduu, off the west coast of Babeldaob, and several areas in the southern lagoon (Chelbacheb) and eastern lagoon. The second expedition, in June 1992, covered the six southwest islands. The third expedition, in August 1992, covered the east coast of Babeldaob, Orak, Ngeream, Malakal, and Koror Islands and a few southern lagoon sites. The fourth expedition covered northern reefs and atolls, the northern lagoon (Toachel Ngkesol), portions of the southern lagoon, some major islands in the lagoon (Peliliu, Ngerekebesang, Mecherchar, Ulong, Ngeruktabel, etc.), parts of the west coast of Babeldaob, and Angaur Island just to the south of the barrier reef (see Fig. 1). A total of 184 field sites were surveyed during the 10 weeks of field time for the REA, resulting in fairly complete coverage for the entire archipelago of Palau. Important resource surveys completed since 1990 are summarized in Table 1a, b.

Excellent maps of Palau were prepared at a scale of 1:25 000 by the US Army Map Service during the 1940s and 1950s and by the US Geological Survey during the 1980s. In preparation for the REA, low-altitude color aerial photographs were taken over every island and coral reef in Palau during April and May 1992. The photographs were taken mostly at a scale of 1:20 000, with some at larger scales (1:4000–1:8000). The film area for each photograph measured 522 cm^2, allowing detailed analysis of small to large scale reef features. Knowledgeable Palauans participated in photo-interpretation and recommended many sites worthy of field examination.

Exact details of techniques used during underwater surveys varied according to the investigator and subject, but all involved underwater observations recorded during a half hour scuba dive at each site. The use of preprinted waterproof forms accelerated the recording of notes underwater. For example, one set of forms included a list of coral species previously reported from Palau and space to add new species records. Species present at a site were checked on the list. At the end of the dive the relative abundance of each species was estimated using a five-point scale–dominant, abundant, common, occasional, and rare. Space was also available on the forms to sketch a cross-sectional profile of the reef, describe the condition of the reef, estimate total percent live coral cover, and make notes on water visibility, currents, and wave action. On reef slopes each half hour survey began at a depth of 20 m. Divers then began to ascend slowly to the top of the reef. Horizontal distances during ascent averaged 100 m in the absence of currents. Otherwise divers drifted with the current. The half hour time limit was normally sufficient to record all coral species because of the preprinted list of species on the forms. However in some cases a few more minutes was spent on recording species seen during the previous half hour. Comparable information was also collected for reef and shore fishes (Donaldson 1992, 1993), other marine invertebrates (Richmond 1991; Birkeland and Richmond 1992; Smith, in preparation), and marine algae (McDermid 1993). Notes were also taken on sea turtles encountered during the dives and on oceanographic and water quality conditions (currents, turbidity, etc.)

One member of the team was responsible for taking underwater video at each site. Use of underwater video greatly assisted the entire team in characterizing each reef site and recording observations. About 5–10 min of coverage was taped at each site using Sony Hi8 video equipment and tape. The video footage was an important check against earlier reef profile sketches and estimates of relative coral abundance, especially for dominant and abundant species. Video coverage often revealed a few species of corals not seen by the coral observer during the surveys.

The maps and aerial photographs were used in calculating the area and length of selected reef habitats, using planimeters and map measures.

Table 1. **a** Summary of the technical reports prepared as a part of the 1992 Palau Rapid Ecological Assessment and 1991 Ngeremeduu Bay assessment. **b** Additional recent technical reports summarizing the status of other important species and areas in Palau

Subject	References
Archaeology (SW Is.)	Hunter-Anderson (1993)
Ciguatera and contaminants (Koror)	Lobel (1992)
Freshwater biota (Babeldaob)	Bright (1991), Smith (1991), Honigman (1992)
Seabirds and land animals	Di Rosa (1992), Kepler (1993)
Marine invertebrates (other than stony corals)	Richmond (1991), Birkeland and Richmond (1992)
Marine plants	Gordon (1991), McDermid (1993)
Nearshore fishes	Amesbury (1991), Donaldson (1992, 1993)
Reefs and stony corals	Maragos (1991, 1992a), Maragos and Meier (1993a, b)
Resource use assessments	Kitalong (1991), Des Rochers and Matthews (1992)
Sea turtles	Geermans (1992), Di Rosa (1992), Maragos (1992b), Guilbeaux (1992), Geermans and Honigman (1993)
Vegetation (Ngeremeduu Bay and Southwest Islands)	Canfield et al. (1992), Kepler (1993)
Sea water crocodiles	Messel and King (1991), Brazaitis (1992)
Nearshore fisheries	Preston (1990), Kitalong and Oiterong (1991)
Dugongs	Marsh et al. (1992)
Forest birds	Engbring (1992)
Bats	Wiles and Engbring (1993)
Ngerukeuid Islands Wildlife Preserve	Birkeland and Manner (1989)
Coastal development sites	Birkeland et al. (1989)

Physiography

Palau is the westernmost archipelago in the Pacific Ocean and is located at latitudes 6°53′ to 8°12′ N and longitudes 134°08′ to 134°44′ E (Fig. 1). The main Palau Islands are 740 km east of Mindanao and 1300 km southwest of Guam. The archipelago stretches 800 km from Velasco Reef and Ngeruangl Atoll in the north to Helen Atoll and Tobi Island in the south. The archipelago consists of 8 large, 12 intermediate and 566 small islands (Fig. 1). The main islands, between Babeldaob and Peliliu Islands, encompass a distance of about 125 km. Coral reef habitats in terms of area, length and type are summarized for each of the 16 political subdivisions or states of Palau (Table 2).

The archipelago extends northeast to southwest along the Palau ridge, a submerged geological feature stretching from the Mariana and Yap Islands in the north to Irian Jaya in the south. All but 11 of Palau's 586 islands are clustered in the "main" islands. Due to tectonic activity, many of the main islands consist of reefs thrust above sea level, including the rock islands (Chelbacheb), Peliliu Island and Angaur Island. Most of the largest islands are volcanic, including Babeldaob (332 km^2), Ngerekebesang (5.2 km^2), Malakal (2.3 km^2), and part of Koror (9.13 km^2). A large deep pass (Toachel Mid) cuts through the main islands from west to east, and Koror is the only volcanic island south of the pass. Two low-lying coral atolls (Ngeruangl, Kayangel) and a submerged reef (Velasco) occur to the north of the main islands. Five low-lying coral islands (Sonsorol, Fana, Pulo Anna, Merir, Tobi) one atoll (Helen), and one raised coral island (Angaur) lie between 10 and 600 km south of the main islands (Fig. 1).

Results of observations on corals and reefs

Previous research on coral reefs in Palau is summarized in UNEP/IUCN (1988). For corals, the first observations were by Rehberg (1892). Later, Japanese marine biologists conducted reef studies centered at the Palao Biological Station near the urban center at Koror. Much of the research focused on systematics, physiology, and basic biology, although some ecological surveys were performed at "Iwayama Bay" to the south of the town on Koror, including studies on corals (Eguchi 1936; Abe 1937; Abe et al. 1937; Matsuya 1937; Motoda 1939; 1940a, b). Eguchi (1938) described 170 species of corals from Palau, mostly from Iwayama Bay.

Contemporary research on Palau's corals and reefs were accomplished by visiting scientists from the nearby University of Guam. One study involved an assessment of sewage outfall impacts at Malakal (Birkeland et al. 1976), and another focused on a proposed resort at Ngerekebesang (Randall et al. 1978). Faulkner (1974) and Faulkner and Chesher (1979) also published photographic essays of Palau's reef and corals that focused worldwide attention on Palau's spectacular coral reefs and "rock" islands. More recently coral reef surveys have concentrated in the southern lagoon and rock islands. Reef and terrestrial habitats were surveyed at the Ngerukeuid ("70 Islands") Reserve, Micronesia's only marine protected area (Birkeland and Manner 1990). Surveys of Kayangel Atoll were also accomplished in 1974 as part of a regional ecosystem survey of the South Pacific (Dahl 1980). An excellent inventory of wetlands, including mangroves, was completed for Palau by Stemmermann and Proby (1978). A coastal ecological survey of proposed construction sites on Babeldaob and Koror was also accomplished by Birkeland et al. (1989).

Palau's islands and coral reef ecosystems can be conveniently divided into seven regions as described below.

Northern islands and reefs

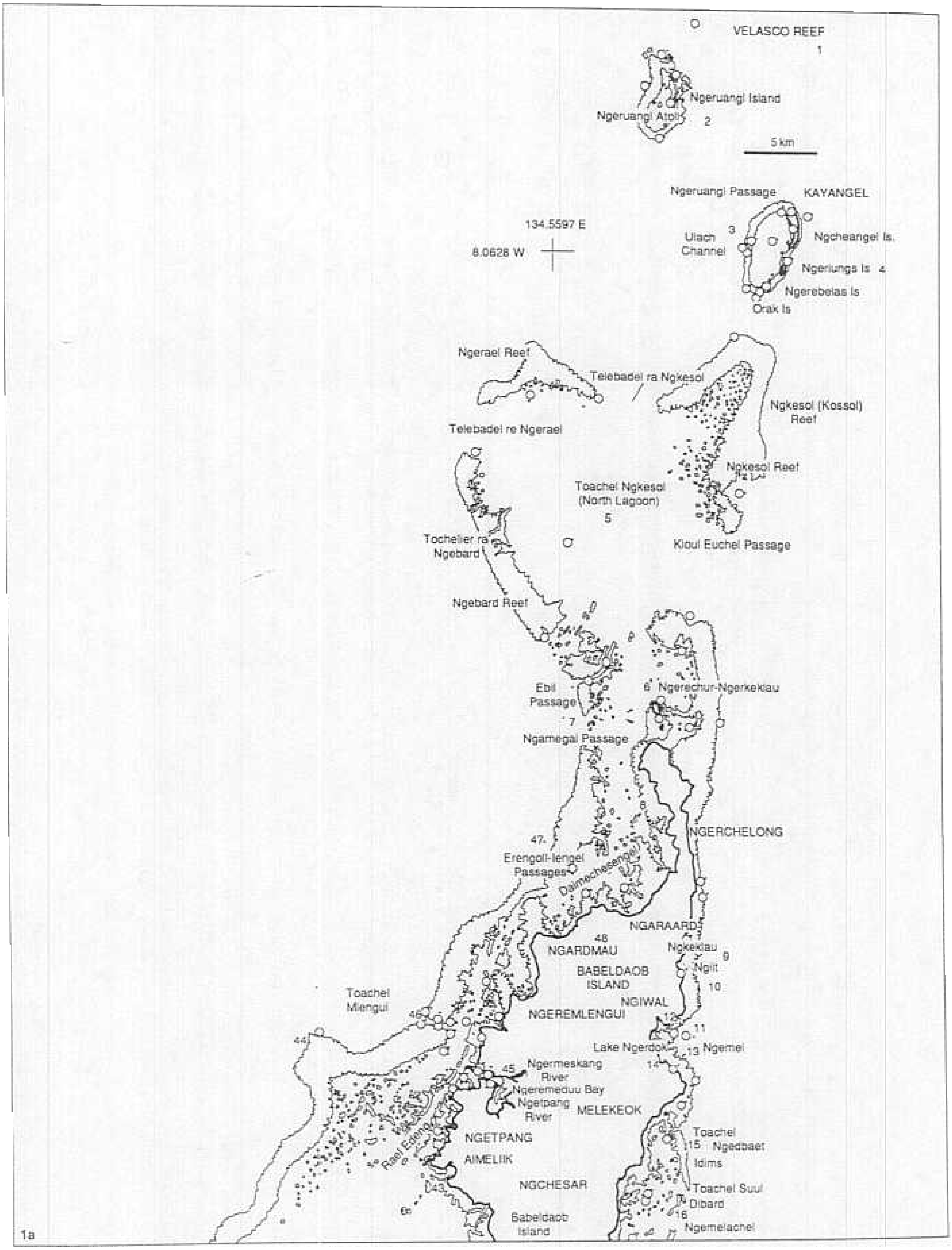
The northern reefs consist of Velasco Reef (a submerged atoll-like reef), Negeruangl Atoll, and Kayangel Atoll. Much of Velasco Reef is uncharted and it extends 32 km north of Ngeruangl Atoll at the southern end of the reef. Velasco is oval shaped and has a maximum east-west width of 16 km. The central depression ("lagoon") is 31–55 m deep, while the rim is 15–20 m deep. Ngeruangl Atoll has a single unvegetated island, a shallow lagoon with an average depth of 6 m, and about 115 pinnacle and patch reefs. A single tortuous deep pass cuts through the perimeter reef on the southeast side. The lagoon floor is covered with thick sand deposits and thickets of staghorn *Acropora*. Heavy wave exposure limits coral diversity and cover on Velasco Reef.

Kayangel Atoll is located only 3 km north of the northeastern tip of the barrier reef encircling most of the main islands. Beaches off both atolls were important nesting sites for sea turtles but nesting frequency has declined. Uninhabited Ngeruangl Island is also important for nesting sea birds and a few fruit bats previously roosted on Kayangel (Kepler 1993).

Kayangel has four small vegetated islands, the largest of which (Ngcheayangel) is inhabited. Narrow seagrass beds and sandy beaches fringe the larger islands. The lagoon has an average depth of 6 m and a maximum depth of 9.5 m, and about 25 large pinnacles can be detected from aerial photographs. One shallow pass bisects the perimeter reef on the west. Coral diversity and abundance are low in the lagoon. Large fish, dolphins and foraging sea turtles are common near the pass.

Northern barrier reef and lagoon

The club-shaped northern barrier reef complex extends 31 km north of Babeldaob, enclosing a large lagoon area (Toachel Ngkesol) measuring 325 km^2. The lagoon deepens from north (13–21 m) to south (38–50 m) and is filled with many mounds, pinnacles, patch reefs, and reef holes. Two small, high limestone islands (Ngerkeklau, Ngerechur) are situated in the northern lagoon just north of Babeldaob. Expansive seagrass beds are found on the reef flats fringing the lagoon shoreline of northern Babeldaob and extend up to 2 km offshore. Six large deep passes (Kloul Euchel, Telebadel ra Ngkesol, Telebadel ra Ngerael, Ngamegai, Ebil, and Erengoll-Iengel) cut through the northern barrier reef. The passes are progress-


VELASCO REEF
1
Ngeruangl Island
Ngeruangl Atoll
2
5 km
Ngeruangl Passage
KAYANGEL
134.5597 E
8.0628 W
Ulach Channel
3
Ngcheangel Is.
Ngeriungs Is
4
Ngerebelas Is
Orak Is
Ngerael Reef
Telebadel ra Ngkesol
Ngkesol (Kossol) Reef
Telebadel re Ngerael
Ngkesol Reef
Toachel Ngkesol (North Lagoon)
5
Tochelier ra Ngebard
Kloul Euchel Passage
Ngebard Reef
Ebil Passage
6 Ngerechur-Ngerkeklau
7
Ngamegal Passage
8
NGERCHELONG
47
Erengoll-lengel Passages
Dalmechesengel
NGARAARD
48
NGARDMAU
Ngkeklau
9
Ngiit
10
BABELDAOB ISLAND
Toachel Mlengui
NGIWAL
12
46
NGEREMLENGUI
11
44
Lake Ngerdok
13 Ngemel
14
45
Ngermeskang River
Ngeremeduu Bay
Ngetpang River
MELEKEOK
Rael Edeng
NGETPANG
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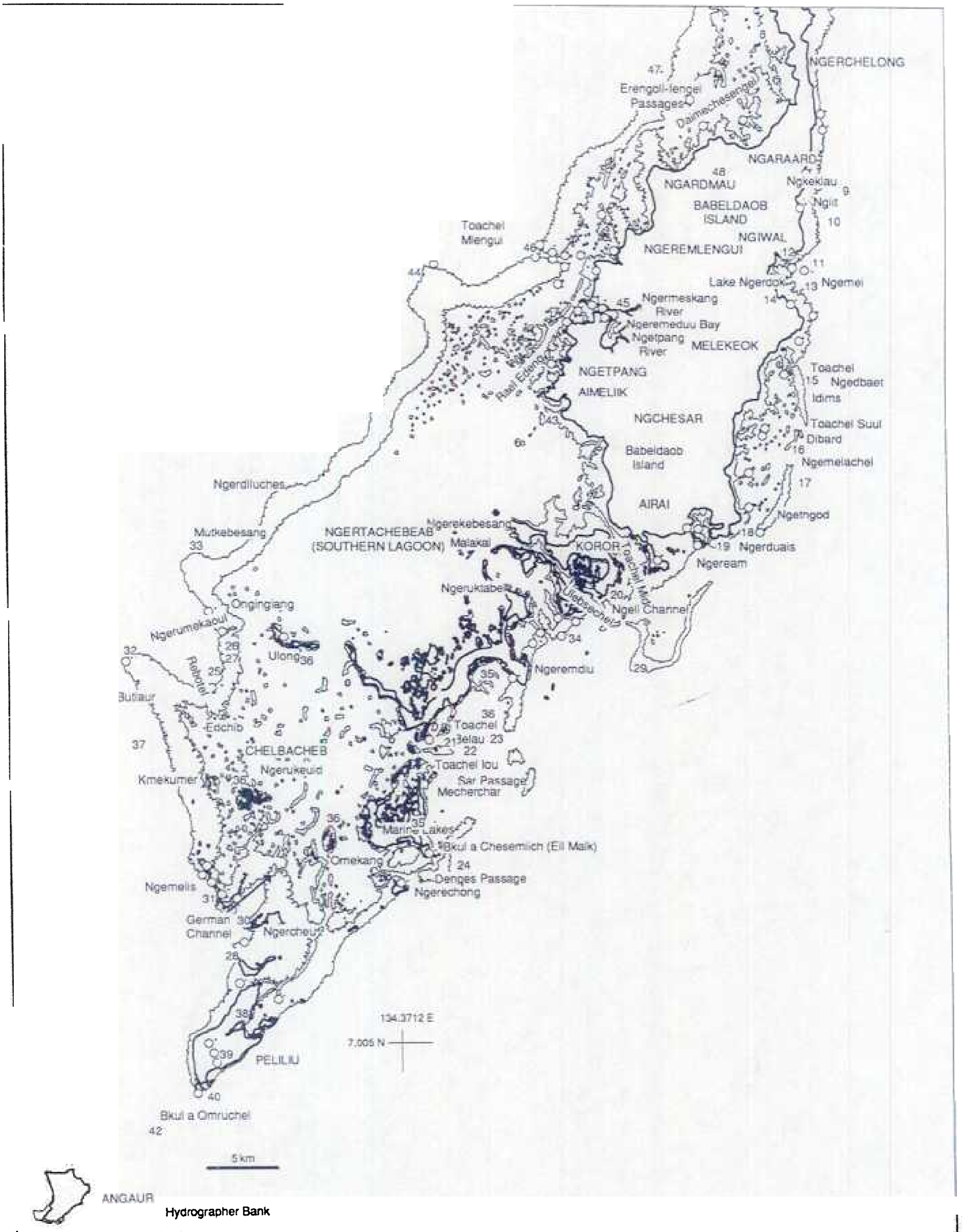
Toachel
15 Ngedbaet
Idims
NGCHESAR
43
Toachel Suul
Dibard
16
Ngemelachel
Babeldaob Island
1a


NGERCHELONG
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NGARAARD
NGARDMAU
Ngkeklau
Ngiit
BABELDAOB ISLAND
Toachel Mlengui
NGIWAL
NGEREMLENGUI
Lake Ngerdok
Ngemei
Ngermeskang River
Ngeremeduu Bay
Ngetpang River
MELEKEOK
NGETPANG
AIMELIIK
Toachel Ngedbaet Idims
NGCHESAR
Toachel Suul Dibard
Babeldaob Island
Ngemelachel
Ngerdiluches
AIRAI
Ngetngod
Mutkebesang
NGERTACHEBEAB (SOUTHERN LAGOON)
Ngerekebesang
Malakal
KOROR
Ngerduais
Ngeream
Ngeruktabel
Ngell Channel
Ongingiang
Ngerumekaoul
Ulong
Ngeremdiu
Butiaur
Edchib
Toachel Belau
CHELBACHEB
Ngerukeuid
Toachel Iou
Kmekumer
Sar Passage
Mecherchar
Marine Lakes
Bkul a Chesemiich (Ell Malk)
Omekang
Denges Passage
Ngerechong
Ngemelis
German Channel
Ngercheu
134.3712 E
7.005 N
PELILIU
Bkul a Omruchel
5 km
ANGAUR
Hydrographer Bank

1b

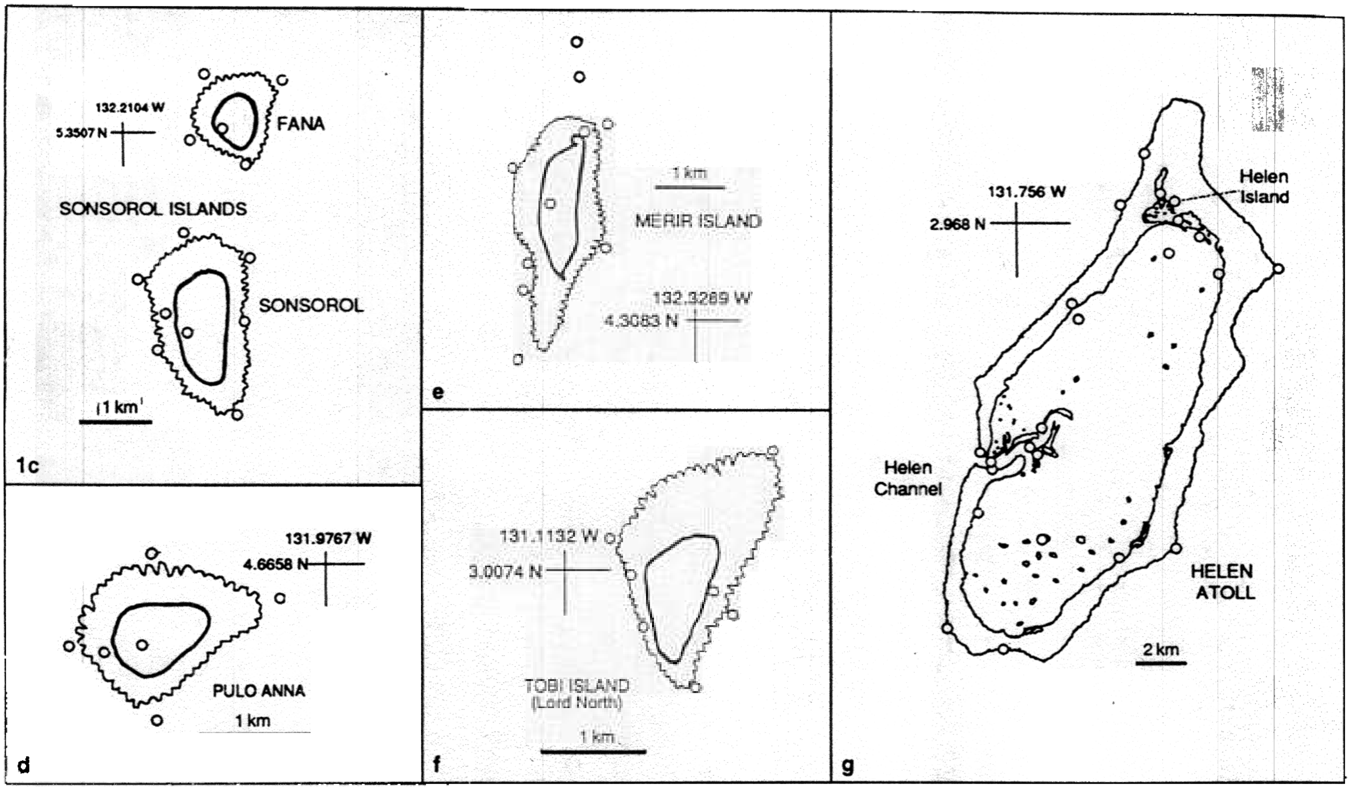

Fig. 1a–g. Maps of the Palau Islands and reefs, showing shorelines (bold lines), shallow reef margins (thin lines), REA field sites in 1991—1992 (open circles), approximate locations of proposed protected areas (numbers), place names (lower case), and political subdivisions and regions (upper case). **a** Northern half of main islands; **b** southern half of main islands; **c–g** Southwest Islands: **c** Sonsorol and Fana, **d** Pulo Anna, **e** Merir, **f** Tobi, **g** Helen. All maps oriented with true north at the top

Table 2. Summary information on Palau's coral reefs and mangroves (after Maragos and Meier 1993b)

State	Mangrove km²	Fringing reefs		Lagoon and passes			Barrier reefs		Atoll reefs		Reef Holes No.	Island No.[a]	Total area[a] km²
		km²	km	km²	km	No. patch reefs	km²	Ocean side km	km²	km			
Aimeliik	2.8	8.2		55.0		231	27.0		0	0	40	2	93.0
Ngetpang	6.3	2.7	189.9	15.0	79.7	14	7.1	57.4	0	0	2	17	31.3
Ngeremlengui	4.0	7.5		15.0		16	12.3		0	0	14	0	38.8
Ngardmau	7.2	13.8		22.5		16	11.0		0	0	141	0	54.5
Ngerechelong	2.1	23.0	20.8	325.0	141.5	240	813	62.7	0	0	15	2	499.1
Ngaraard	3.4	23.2		23.8		43	17.3		0	0	5	2	67.7
Ngiwal	1.3	5.8	58.5	12.1	50.9	0	0	22.0	0	0	0		19.2
Melekeok	1.7	8.4		0		0	0		0	0	0	2	10.1
Ngchesar	1.8	6.9		23.0		86	4.7		0	0	7	1	36.4
Airai	7.9	22.7	11.6	30.0	20.1	17	4.0	6.8	0	0	87	41	64.6
Koror	1.6	19.2	–	500.0	112.8	683	100.0	86.4	0	0	100	491	620.8
Peliliu	4.9	35.5	12.7	0	0	1	0	0	0	0	5	13	40.4
Angaur	0	2.6	13.4	0	0	0	0	0	0	0	0	4	2.6
Sonsorol	0	8.3	25.5	0	0	0	0	0	0	0	0	2	8.3
Tobi	0	7.0	2.0	103.0	53.8	85	0	0	57.9	61.7	2	2	333.7
Kayangel	0	2	0	12.1	9.6	25	0	0	7.1	13.6	0	5	19.2
Total	45.0	194.8	334.4	1136.5	468.4	1457	264.7	235.3	65.0	75.3	418	585[a]	1939.7

[a] Excludes Babeldaob, which is divided into 10 states, and which would constitute the 586th island in Palau

ively deeper and narrower in a counter-clockwise direction from SE to SW. Portions of the northern lagoon supported large schools of reef fish (Donaldson 1993) and moderate to high coral diversity and coverage (Maragos and Meier 1993b). Manta rays were reported in the passes. The highest coral development on the northern reefs occurred along the steep west-facing ocean reef slopes (60–70% cover). The reef slope is not as steep along the east coast, where well-developed spurs and grooves occur along the upper margin.

East coast of the main islands

The eastern coral reefs extend mostly off Babeldaob Island between the northern lagoon and the southern lagoon. In the north between Ngerechelong and Ngiwal is a fringing reef; this is the only sector around the main islands lacking a barrier reef and lagoon. South of Ngiwal to Melekeok, the reef is a transitional type between fringing and barrier reef. Off Ngchesar to Airai a well-developed barrier reef and narrow lagoon complex is found off the eastern coast. The east-west channel Toachel Mid separates the northern and southern reefs, islands, and lagoons.

The coral reef ecosystems are diverse, including extensive mangrove fringes south of Ngaraard and white sand beaches north of Ngaraard. Seagrasses are also extensive off Ngiwal and on Ngerechelong and remain abundant along the rest of the eastern coast. Spur and groove formations are well developed off the upper eastward ocean-facing reef slopes and are better developed to the north. Dugongs were frequently sighted in the beds (Marsh et al. 1992). Ocean reef slopes are steep and show high coral cover and diversity. Some pass and lagoon reef sites also exhibit high coral abundance and diversity and are dominated by suspension feeders. Some damage from storms (especially Typhoon Mike in 1990) was evident along the northern end of the reefs where coral diversity and cover are lower. Sediment damage from previous airport construction, dock construction and ongoing road construction has also degraded reefs in Airai Bay to the south and off Ngchesar and Melekeok to the east. Reef holes are numerous (87), and 40 small, high limestone islands are found along the coast, mostly near the southern end. Six channels and five passes (Toachel Ngedbaet, Toachel Suul, Ngemelachel, Orakibad, Toachel Mid) cut through the fringing and barrier reefs.

Western coast off Babeldaob

The coral reef ecosystems off western Babeldaob support the most extensive fringing reefs, mangrove swamps, freshwater swamps and estuaries in Palau, and the barrier reef, seagrass beds, and lagoon are also extensive. The northwestern lagoon is also the most important feeding grounds for the dugong, an endangered marine mammal (Marsh et al. 1992) and the salt water crocodile (Messel and King 1991; Brazaitis 1992). Ngeremeduu Bay, including surrounding watersheds and offshore reefs, is the most prominent feature of the coast and includes representatives of most major ecosystem types found in Palau. The fringing and barrier reef complex contains numerous reef holes (204) and patch reefs (500), and the lagoon is deep throughout (25–50 m). The fringing reef is long (190 km), as is the barrier reef (44 km). The lagoon slopes generally support higher coral coverage and diversity and a great variety of suspension-feeding hard and soft corals. The reef flats support abundant sea cucumber populations (Richmond 1991). A total of 19 small islands are found along the west coast of Babeldaob and are mostly of volcanic origin. Only three large passes occur along the entire western coast of the main islands. The northernmost (Iengel) is 10 m deep and 570 m wide. The second pass Deimechesengel, a few kilometers to the south, measures 760 m in width and 44 m in depth. A strong feeder current system (Real Edeng) runs the long distance along the lagoon from Deimechesengal to the next pass to the south, Mlengui. To the south of Mlengui, the next pass is 85 km away at Ngemelis. The western passes are among the most important in Palau for fish migrations and they support high diversity and abundance of corals and fish. Coral coverage and diversity are moderate to high on ocean-facing reef slopes.

Southern lagoon

South of the main east-west channel of the main islands (Toachel Mid) is the southern lagoon and barrier reef complex, covering an area of 500 km^2, the largest in Palau. Although fringing reef development is low (22.7 km^2 area and 11.6 km length) the barrier reefs are very extensive, covering 100 km^2 and having a length of 86 km along the ocean perimeter. The region also has the greatest number of patch reefs (683) and the greatest number of islands (491), mostly raised limestone islands. The islands support rare species of plants and birds (Birkeland and Manner 1990; Engbring 1992). Reef holes (100) are common, but mangroves are poorly developed and confined to Koror Island and the northeast side of Pelilu. Seagrass beds are well developed off the three large islands of the urban center in the north (Koror-Malakal-Ngerekebesang) and off the southern reefs north of Peliliu Island. The entire southwestern side of the barrier reef lacks passes and only the dredged German Channel near the southern end of the reef at Ngemelis affords subtidal exchange between the lagoon and ocean. The southeast side of the barrier reef has several gaps and passes between the ocean and lagoon. Immediately southwest of the urban complex are found numerous small to large high limestone ("rock") islands, sublagoons, marine lakes, and reefs. The lakes are unique in lacking a surface connection to the lagoon or ocean. The lakes number 67 and are found mostly within the interior of the larger limestone islands (Peliliu, Syngall-Koror, Ulebsechel, Ngeruktabel, Mecherchar). Some lakes support unique aquatic ecosystems (Hamner and Haurl 1981; Hammer 1991). Beaches are small but numerous and support the most important nesting habitat for hawksbill turtles in Micronesia. The beaches are also popular picnic sites for residents and visitors, and Palau's most popular diving sites are located on the southern portion of the southern lagoon and barrier reef. Giant clams and fish were previously more numerous but are now heavily harvested because they are popular delicacies. Many reef points, passes (including Denges and Sar) and dead-end channels off the southwest perimeter (Ngeumekaoul, Rebotel, Ongingiang) are sites of seasonal fish spawning aggregations. Feeding green and hawksbill turtles are numerous in the southern lagoon and around Peliliu (near the seagrass beds). The salt water crocodile is also common off Peliliu's mangroves, and feeding dugongs are common on the seagrass beds off Sar Passage and Malakal Harbor. Nautiloids are also common off the deep steep slopes of the southeast perimeter.

Extensive studies were recently conducted in Ngerukeuid Island (2–6 km^2), as part of the long-range planning and monitoring for Palau's only marine protected area (Thomas et al. 1989; Birkeland and Manner 1990). In 1991 and 1992, other sites were also surveyed in the south lagoon as part of the REA. Coral abundance and diversity varies from moderate to high on lagoon slopes and passes to high in the dead-end channels. During a 45-min survey in Ngermekaoul dead-end channel in 1991, over 90 species of corals were recorded with some individual coral colonies measuring 25 m across and 10 m in height. Ocean reef slopes are steep and support moderate to high species diversity and abundance. Off Malakal Harbor the only important crown-of-thorns starfish aggregation in Palau was observed; it is situated in the same location as was previously reported (Birkeland et al. 1976) and has not spread to other areas (C. Birkeland, personal communication).

Peliliu and Angaur

Peliliu (12.7 km^2) anchors the southern end of the barrier reef, and Anguar (8.4 km^2) is situated 10.5 km to the southwest in the open ocean. Both are inhabited, and are raised limestone islands. Small boat basins were blasted out of the fringing reef off the west coasts of both islands. Sea turtle nesting has declined to low levels off Peliliu's broad western beaches and is also declining off Angaur. Fringing reefs and steep ocean reef slopes are the dominant reef habitats, except off the northeast lagoon shore of Peliliu, which supports extensive mangroves and seagrass beds. Mangroves are absent off Angaur, but a small seagrass bed is found along the southwest coast. Coral abundance and diversity is low to moderate off Peliliu, but fish diversity and abundance is very high. Coral coverage was very high along the western ocean slopes of Angaur, and diversity was high along the eastern slopes.

Southwest Islands

The six Southwest Islands south of Angaur are 340–600 km south of the main islands. The southernmost is Helen Atoll, a true atoll with one deep pass, a lagoon measuring 103 km^2 and containing about 85 patch and pinnacle reefs, and one small vegetated low coral islet (Helen Island) measuring 3 ha in area. Elsewhere, the remaining five islands (Tobi, Merir, Pulo Anna, Sonsorol and Fana, from south to north) are low coral islands resting atop table reefs lacking lagoons, and the dominant habitats consist of reef flats and slopes exposed to open ocean conditions. All islands except Fana are inhabited; Helen has only been recently occupied on a permanent basis. Helen supports one of the largest sea turtle feeding areas in Palau and until recently supported high levels of sea turtle nesting activity, which is now declining. Merir still supports the largest green turtle nesting activity in Palau, but present sea turtle harvesting levels are not sustainable (Geermans 1992). Helen supports the largest sea bird nesting populations, although there have been recent declines owing to human disturbance and harvesting. Sea bird populations are also abundant and diverse on uninhabited Fana Island (Kepler 1993). Coral diversity was very high at Helen Atoll. Elsewhere in the southwest islands coral species diversity is lower. Reef fishes showed similar patterns, with the highest values reported at Helen, where coral reef habitat abundance is higher and more diverse than all the remaining southwest islands combined. Illegal or excessive harvesting of giant clams has been reported from Helen Atoll (UNEP/- IUCN 1988), and some evidence of overharvesting was apparent during field observations. Fuel spills and ship groundings have also been reported recently in the Southwest Islands.

Discussion

The status of Palau's nearshore marine ecosystems

Before the 1992 REA, coral reef ecosystems in Palau had not been well evaluated by scientists except in a few areas, preventing accurate comparative evaluation throughout the whole archipelago. By relying principally on qualitative techniques, experienced investigators were able to sample adequately all regions and all major habitats in a total of less than 3 months field time. Interviews with knowledgeable islanders beforehand helped to focus the efforts of investigators at many key locations. For most sites the characterization by interviewed islanders were accurate, informed, and helped scientists to save time in the field during surveys. The REA and other recent studies reveal that coral reefs in Palau are in excellent condition, supporting diverse and abundant coral reef, seagrass, mangrove, and lagoon ecosystems. At present only a few coral reef areas have been subjected to anthropogenic impacts, mostly from soil erosion attributed to previous airfield and ongoing road construction and some land clearing, especially along southern Babeldaob Island. The population of Palau is small (approximately 15 000) and two-thirds live in the urban center of Koror (Oreor) Island. Dredging and filling activities have caused some damage to mangroves, seagrasses and coral reefs around Koror, Malakal, Ngerekebesang, Peliliu, Angaur and Babeldaob islands. However the extent of damage is not great except at Ngetpang and southern Ngeremeduu Bay of the west coast of Babeldaob where road, fishpond, and dock construction have degraded about 15 ha of mangrove and seagrass habitat and unspecified freshwater swamp habitat. Pollution from the municipal sewage outfall and sanitary landfill disposal areas in the Koror urban area may also be degrading water quality and nearshore habitats, although it is difficult to document the extent of the impacts. Ship groundings and oil spills are always a threat, especially at the low coral island and reef areas; a 1992 ship grounding and spill at Helen Atoll appeared to result in only minor damage.

Although marine resources in Palau appear to be in relatively good condition at the regional/ecosystem level, fishing and harvesting activities have reduced many species, and populations of several species, including dugongs, nesting sea turtles, and crocodiles, are in danger of being extirpated from Palau. In the 1970s crocodiles were hunted for their skins, and dugongs have been traditionally hunted for their meat. The populations of both species have dwindled to very low levels. The green turtle is hunted for its meat and eggs. The rare hawkbill turtle is hunted for its eggs and shell. The latter is fashioned into jewelry that is sold in stores on Palau. Other groups are also heavily harvested including depleted "food" fish, (particularly the bump- headed parrotfish and Napoleon wrasse), trochus, giant clams, coconut crabs, and mangrove crabs. Aquarium fish and "food" fish are also harvested in heavy numbers and shipped to nearby overseas markets. Although fruit bats are no longer exported, they were heavily exported from Palau to the Mariana Islands during the past decade.

The greatest threat to nearshore marine ecosystems in Palau stems from the changing political status and economy of Palau. The 1994 transition from a trust territory to an independent nation means that US environmental laws and regulations no longer apply to Palau. Furthermore, the new political-economic relationship between the US and Palau, termed the Compact of Free Association, will provide additional sources of funds for capital improvement and economic development. The relaxation of US jurisdiction is also beginning to fuel large-scale economic development in Palau from foreign investors, especially on Babeldaob, which is relatively sparsely inhabited. Hunting and harvesting of threatened and endangered sea turtles is now increasing. Construction to expand airport capabilities, complete the new capital and expand the road network on Babeldaob are also leading to land clearing and potential soil erosion, which is causing sedimentation in coastal waters. Fortunately, most of Babeldaob is encircled by an intact mangrove fringe which serves as a protective barrier, impeding sedimentation in coastal waters. However several swamps have been degraded or destroyed by clearing, excessive soil deposition, and landfill expansion for docks and urban development. Clearly, planning for future development and conservation is needed to maintain the high quality and diversity of Palau's coral reef and related ecosystems.

The preliminary results of the REA (Maragos et al. 1993, 1994) have been passed on to Palau government leaders and the preparers of Palau's new master plan for economic development. The REA led to development of criteria and categories of protected areas (Tables 3, 4) and to the identification of about 45 marine ecosystem areas warranting specialprotection due to a combination of high value and/or imminent threat to habitats or species (see Table 5, Fig. 1). Exact boundaries for these areas were not delineated since full discussion with the community and resource users had not been completed at the time of writing. The REA to date has focused primarily on marine and coastal ecosystems, although some recommendations have also been directed toward the protection of upland species and ecosystems. For example, important habitats for rare birds, roosting fruit bats, and endemic freshwater species have been proposed for protection. Aside from recommending the designation and management of a system of protected areas, the REA also led to recommendations to control fish harvesting activities and targeted several groups of rare species for special attention, including sea turtles, crocodiles, dugongs, fruit bats, coconut crabs, giant clams, top shell, and certain bird species. Many of the recommendations in the REA were based upon feedback from local governments and islanders during the interview phase of the assessment. For example, the states of Kayangel and Tobi advocated greater levels of protection for the natural resources at Palau's three atolls: Helen, Ngeruangl, and Kayangel. State governments also requested greater cooperation with the national government in enforcing local conservation ordinances and in respecting the customary tenure and resource management regimes which have operated successfully over millenia to sustain the productivity of harvested species and habitats. However on some remote islands (Tobi for example) much of the population has moved to the Koror urban center and many traditional practices and tenure are no longer followed.

Table 3. Criteria used to identify specific ecological areas as candidates for protected areas. Letter codes correspond to those listed in Table 5

a	*Critical habitat for rare species*: including endemic, rare, threatened, endangered, or depleted species, such as giant clams, coconut crabs, salt water crocodiles, ses turtles, dugongs, and megapodes
b	*Peak habitat for other important species*: especially aggregation sites for edible species of fish that are heavily harvested
c	*Areas of unique species communities or ecosystems*: for example, nautiloids, sea snake aggregation sites, marine lakes, and freshwater lakes (the last of which are rare in Palau)
d	*Areas supporting several to many important ecosystems*: sites where a variety of ecosystems or habitats are concentrated in a smaller area, such as Ngeremduu Bay where eleven major ecosystem types are found in the watershed and offshore waters
e	*Important ecological areas supporting several to many rare or important species*: areas where two or more rare or important species are concentrated, for example, the large seabird and turtle nesting sites at Helen Island
f	*Other important ecological areas already established by national state or traditional laws or controls*: for example, many fish aggregation and trochus areas are established as conservation areas and reserves. Also included is the Ngerukeuid ("70 Islands") Ecological Reserve, the only established protected area in Palau affording full protection to all species
g	*Important ecological areas threatened with development, habitat destruction, or overharvesting of key resources*: for example, mangrove swamps, seagrass beds or coral reefs in the path of destruction from road building, soil erosion, resort development, dredging and filling, and chronic solid waste pollution and sewage discharges

Table 4. Types of ecological protected areas recommended for designation in the Palau 1992 REA

National park	Containing a combination of highly significant cultural, historical, esthetic, natural, or ecological attributes and resources of national or international significance. Access controlled through permits and no harvesting or collecting of any type allowed. Actively managed (staff on site)
Ecological reserve	Area containing unique or important combinations of terrestrial, freshwater, estuarine or marine habitats and species
Forest preserve	Area supporting unique or important forest or upland habitat and species of plant and wildlife
Marine preserve	Area supporting unique or important marine habitat or species of plants and animals, especially breeding or aggregation site for rare, unique or important species
Coastal conservation area	Shoreline or beach area supporting important ecological habitat for vegetation and wildlife
Fishery conservation area	Limited entry area for fishery of recreational, subsistence or commercial significance warranting special protec tion or controls to promote sustainable use and avoid over-harvesting and habitat destruction
Tourism site	Visitor destination site with pristine and esthetic value potentially popular for visitation and recreation where special controls are needed to maintain sustainable multiple uses
Special management area	Area proposed for large-scale development (transportation, resort, residential subdivision, golf course, utility) where important nearby ecosystems or species may be threatened unless the development is properly planned and managed

The final draft of Palau's master plan for economic development has been completed and circulated for review to decision-makers and the general public. Roughly 90% of the REA recommendations were incorporated into this final draft, and upon the document's approval, implementation of this section should begin sometime in 1995. For the purposes of an independent review of the REA findings, the master plan's environmental consultant surveyed several state officials in Palau to ascertain what natural areas they believed to be important for future protection efforts. There was some 75% overlap in priority area identification between the states' suggestions and those of the REA. Provided that a system of protected areas is formally designated in Palau, their monitoring and on-site enforcement will be crucial for maintaining important ecosystems and many heavily harvested species.

The REA to date also led to other recommendations to improve the environmental impact assessment (EIA) process for development planning, to initiate a long-term coral reef monitoring program, and to provide special technical and educational assistance to better design, site, and construct special types of development, particularly roads and resorts. Most importantly, the preliminary results of the REA were completed in time to be available at the beginning of the process to develop the master plan for economic development. The authorization and designation of protected areas in that plan and proper execution of EIA, conservation, and enforcement programs should contribute measurably to the sustainable use of Palau's nearshore marine resources.

The role of REA in coral reef management

Rapid Ecological Assessment represents an increasingly important technique and opportunity for social and biological scientists to contribute to the conservation of important ecosystems and species, especially where time, funding and geography pose constraints on more orderly scientific scrutiny and research. For example, there are very few coral reef scientists in the many island groups in the tropical Pacific, and the great majority of reef areas have never been visited by scientists (Maragos et al., in preparation). Fewer scientists are actively engaged in coral reef management activities such as monitoring, pollution impact assessment, restoration, protected areas management, coastal zone management, and rapid ecological assessment. Most of these scientists are focusing on coral reefs near urban areas where logistical problems are more easily solved, where a variety of stresses to reefs are concentrated (e.g. solid waste and sewage pollution, industrial discharges, coastal construction, overharvesting of fisheries), and where political will and funding for research is concentrated. As a result, scientific resources are very limited and most often do not anticipate and cannot respond to the need for scientific scrutiny and input to help guide future economic development in a manner that avoids or reduces costly impacts on important ecosystems.

In this study the participation of outside scientists had to be limited and efficiently organized as a result of time and funding constraints. Nevertheless, considerable lead time was needed by The Nature Conservancy in Palau to build up rapport and respect to convince island leaders of the potential value of an REA. This was especially important because all management and protection of Palau's ecosystems will be borne by Palauan residents and leaders. In the case of Palau, the REA was designed to cover the entire archipelago and provide recommendations to government officials and consultants working on the master plan for economic development, and for village-based resource users who share marine resource management responsibilities with the government in Palau. The short study

Table 5. Sites proposed as protected areas in Palau, arranged from north to south (after Maragos et al. 1994b). See Tables 3 and 4 for explanation of selection criteria and types of protected areas. See Fig. 1 for location of each site corresponding to the numbers in the left column

Name and location	Type	Selection criteria	Coverage
Velasco Reef (all) 1	Fishery conservation area	a, b, g	All marine habitats and species to 100 m depth
Ngeruangl Atoll (all) 2	Ecological reserve	a, e	Nesting wildlife, all marine species, island and coral reef ecosystems
Kayangel Atoll (Ulach) 3	Fishery conservation area, tourism site	b, c, e, g	All marine habitats and species in channel
Kayangel Atoll (Ngeriungs and Ngerebelas) 4	Coastal conservation area	e, g	Nesting sea birds, megapodes, sea turtles, fruit bats, coconut crabs
Northern lagoon (all) 5 (Ngerechelong)	Fishery conservation area	b, c, f, g	All harvested species
Ngerchur and Ngerkeklau Island beaches (Ngerechelong) 6	Coastal conservation area	a	Nesting sea turtles
Ngerechelong and Ngaraad seagrass beds 8	Marine preserve		Feeding dugongs and sea turtles
Yasumba "snake house" and surrounding reef (Ngaraard) 9	Ecological reserve	c	Sea snake aggregations
Ngiwal seagrass beds 12	Marine preserve	c	Feeding dugongs and sea turtles
Melekeok-Ngiwal forests, lakes, and rivers (Ngerdok) 14	Ecological reserve, special management area	a, b, c, d, e, f, g	Lake biota, crocodiles, rare waterbirds, fruit bats
Ngerduais and Ngeream Island clusters (Airai) 19	Ecological reserve	a, b	Fruit bats, nesting sea turtle, marine lake
Aimeliik 43	Marine preserve	b, c	Mangrove and fisheries habitat
Ngeremeduu Bay 45	Ecological reserve, fishery conservation area	b, d, f, g	Watersheds, estuaries, offshore marine habitats and species
Ngardmau and Ngeremlengui mangroves 47	Fishery conservation area, marine preserve	a, e, f	Dugong and sea turtle feeding areas
Ngardmau savanna 48	Forest preserve	a, b	Forest and endangered birds
Ngemelachel harbor, Ngederrak Reef seagrasses (Oreor) 34	Marine preserve, special management area	a, b	Dugong and sea turtle feeding areas
Ngeruktabel Island (Oreor) 35	Forest preserve	a, b, c, d	Marine lake, forest, bat and bird habitat
Mecherchar Island (Oreor) 35	Forest preserve	a, b, c, d, e	Marine lake, forest, bat and bird habitat
Ulong, Omekang, Kmekumer, and Ngkesiil Island beaches 36	Coastal conservation area	a, c, g	Sea turtle, megapode nesting, forest habitats
Rock Islands Conservation Area (Oreor) 37	National park	a, b, c, d, e, f g	Sea turtles, megapodes, tourist sites, giant clams, coral reefs, marine lakes, forests, etc.
Sar and Denges passes, seagrass flats 23, 24	Marine preserve	a, e	Dugong and sea turtle feeding grounds
Peliliu mangrove and seagrass area 38	Marine preserve	a, b, c, d, e	Seagrass, mangroves, crocodiles, waterbirds, sea turtles
Peliliu forests 39	Forest preserve or national park	b, e, f	World War II battleground, coconut crabs, bird populations
Angaur beaches 41	Coastal conservation area	a, b	Nesting beaches for sea turtles, megapodes, coconut crabs
Barrier reef passes and (many) channels 7, 10, 11, 13, 15, 16, 17 18, 20, 21, 22, 23, 25, 26, 27, 46, 47	Fishery conservation area	b, e, f, g	Spawning grounds, aggregation sites for fish of commercial and subsistence importance, high coral areas, giant clams
Barrier reef points-28, 29, 30, 31, 32, 33, 40, 44	Fishery conservation area	b, e, f, g	Spawning grounds, aggregation sites for fish of commercial and subsistence importance, high coral areas, giant clams
Ngemelis-Peliliu sport diving and fishing sites 40	Marine preserve, coastal conservation area	f, g	Coral and fish-rich areas
Lkes shoal (Angaur-Peliliu) 42	Fishery conservation area	a, b, g	All marine resources

time, limited funding, and large geographic coverage of the REA only allowed for qualitative and semi-quantitative field procedures, but the approach was appropriate for the main objective of the REA to focus attention on identification of a set of candidate protected areas throughout Palau. Under more lenient funding and time constraints, and with the goal of establishing an ecological baseline for longterm monitoring, the field procedures would have incorporated quantitative transect-type surveys at permanently marked sites. In fact, a monitoring program is being initiated in Palau for coral reefs, based upon the feedback from the REA.

Table 6. Comparison of techniques potentially useful for rapid ecological assessments of coral reefs. Techniques used in the Palau REA are marked with an asterisk (*). A combination of techniques, rather than any single approach is advocated for REA

Technique	Strengths	Limitations		References
* Literature review (including maps)	• Access to information from prior surveys • Relocate previous field sites for trend analysis • Maps necessary for resource mapping and distance and area calculations • Assists in field site selection	• Generally inadequate by itself without field verification	• Base maps are essential for any broad-scale REA	Dahl (1981), SPC/UNEP (1984), Maragos and Elliott (1985), Porcher (1993)
* Interviewing knowledgeable scientists and resource users	• Excellent source of long-term trends in ecology and weather • Source of life history data on useful fishery species • Source of information on cultural sites • Assists in field site selection	• Interpretation and translation errors between informant and interviewer • Often difficult to separate opinion from fact • Field verification needed	• Essential for developing conservation and management plans • Build consensus on plans • Encourage comments and suggestions on draft reports	Johannes (1981), Maragos and Elliott (1985), Carpenter and Maragos (1989), Ruddle (1994)
* Aerial photograph	• Excellent for interpreting and mapping reef features, impacts, uses, etc. • Broad geographic coverage possible • Useful for field survey site selection • Aerial photos can serve as base maps in the absence of other maps	• "Ground truthing" needed for verification • Less useful at small scales (<1 to 2 m) • Not useful for censusing reef organisms except large marine mammals and turtles • Expensive if photos not available and need to use aircraft	• Advances in film resolution and sensitivity and in analytical equipment now allow aerial photo interpretation down to the scale of individual coral heads	Hopley (1978), Rützler (1978), SPC/UNEP (1984), Kenchington (1978), van Claasen and Pirrazzoli (1978), Maragos and Elliott (1985), Carpenter and Maragos (1989), Porcher (1993), Rogers et al. (1994)
* Qualitative field observation and bottom reconnaissance surveys	• Allows "big picture" or overview of entire area • Large reef areas can be surveyed per unit dive time • Rough estimates on coral cover, zonation and size • Excellent data on species • Useful for site selection for more detailed surveys	• Not precise for coral abundance and coverage estimates • Not useful for diversity index, evenness, pattern, and density/frequency calculations • Observer biases • Normally requires experienced and knowledgeable scientists	• Can be use with quantitative techniques as the first step in site selection for more detailed surveys or at the same time using two teams, one qualitative and one quantitative	Done (1982a, b), Done et al. (1982), Kenchington (1978, 1988), Pichon (1978), Done and Navin (1990), Rogers et al. (1994)
Observers towed by boats (including manta tows)	• Broad reef coverage per unit time • Rough estimates of coral cover • Good for censusing diurnal, shallow water, large, and easily recognizable benthos • Useful for site selection for more detailed surveys • Excellent for mapping reefs and zones of impacts from fuel spills, bleaching, starfish infestations, storms, etc.	• Generally limited to shallow water • Limitations on data that can be recorded during each tow • Not useful for fish censusing, abundance, and diversity • Not accurate for benthic diversity • Not useful in turbid water • Unsafe near aggressive sharks • Observer biases • Collections or prolonged observations discouraged	• Use of a voice tape recorder/full face mask and a video recorder in lieu of recording data on sheets would allow continuous observations, recording of observations, longer tows between debriefings, and deeper tows	Kenchington (1988), Bass et al. (1989), Moran et al. (1989), Coyer and Witman (1990), Fernandes (1990) Fernandes et al. (1990, 1992), UNEP/AIMS (1993), Done et al. (1982), Moran and De'ath (1992), Rogers et al. (1994)

Table 6. (Continued)

Technique	Strengths	Limitations	Remarks	References
Quantitative bottom surveys and censuses plots, grids, quadrats, plotless, line and belt transects, photo quadrats/transects, chain transects, etc.)	• Very accurate for coral coverage, abundance, diversity indices, evenness, pattern, colony size, distribution, density/frequency, and census estimates • Spatial variability and zonation can be characterized if multiple sites surveyed • Bench mark for long-term monitoring	• Mobilization and demobilization time for transects takes time away from data collection using scuba • Very limited bottom coverage per unit of dive/bottom time • Only rough estimates of species richness unless many sites surveyed	• A reconnaissance survey beforehand would assist in selecting appropriate sites for the quantitative surveys and provide additional information (species richness, bathymetry, geomorphology, etc.) about the larger area surrounding survey sites	Loya (1978), Kinzie and Snider (1978), Dahl (1981), Weinberg (1981), SPC/UNEP (1984), Marsh et al. (1984), Chiappone and Sullivan (1990) UNEP/AIMS (1993), Rogers et al. (1994), Mundy (1991)

Nevertheless, quality control is a concern for REA that relies heavily on qualitative techniques and observations. Under such circumstances it is essential that experenced senior scientists actively participate and direct field surveys and interpretation of results. Comparing the results of qualitative surveys with the results of "spot" quantitative surveys could also serve as a check on quality control and quality assurance.

Ideally, a combination of qualitative and quantitative techniques should be planned for rapid ecological assessments, provided that the study objectives and funding and time requirements are met. Quantitative surveys at fixed locations are required to assess long-range trends at specific sites, but a more extensive qualitative survey beforehand would help in selecting the specific sites for long-term monitoring.

The concept of REA of coral reef environments is not new and many such assessments have been accomplished to date, although addressing different study objectives (Table 6). For example, the manta tow survey technique has been widely used in coral reef environments, especially to assess and map crown-of-thorns starfish densities and live coral cover, and for these purposes the technique is well suited. In fact UNEP/AIMS (1993) has advocated the manta tow technique as part of a standardized methodology to monitor coral reefs worldwise. The advantage of this technique is broader area coverage per unit of observation time plus the collection of data in a format useful for mapping. On the other hand, the manta tow technique by itself is not particularly useful for assessing species diversity on coral reefs and for more precise estimates of coral and fish abundance. In order to increase the accuracy of abundance and diversity estimates, more time must be spent per unit reef area. Given that the number of observers, time, and money will always be constraints in collecting information during underwater surveys, it is essential that the study objectives be clearly defined in advance to determine the appropriate mix of personnel and procedures. For this reason, the development of a standardized set of techniques for surveying coral reefs must take into consideration that the study objectives should dictate the methodology, and that there is no one technique that will serve all purposes. Standardization of methodology should concentrate on formulating a suite of techniques to address a range of different study objectives, and scientists should not be preoccupied with selecting a single technique to address all objectives (see Table 6).

The techniques for long-term monitoring of coral reefs, for examble, would probably include quantitative transect type surveys at fixed and preferably permanently marked sites. However, selection of the monitoring sites is of critical importance, and a prior survey involving other techniques (qualitative observations) would be needed, especially for reefs where there is little information on the distribution and abundance of the organisms and habitats to be monitored. REA could be designed as the initial phase of selecting and establishing a network of monitoring sites. The initial REA could cover a greater area and lead to decisions on which sites should be (or should not be) included in a long-term monitoring study. If the decision were made quickly, the monitoring phase of the survey could then be accomplished immediately after completion of the initial assessment, even during the same field expedition.

Conclusions

Rapid ecological assessment is an important technique for coral reef management and can help guide future management options, especially on reefs where there is very little published or unpublished information. REA can serve as the initial step and for setting priorities in developing marine protected areas, coral reef monitoring, assessing infestations of *Acanthaster* predation, damage assessment following natural disasters (e.g. typhoons, waves, sea level changes), following anthropogenic catastrophes (e.g. ship groundings, oil spills), etc. Aside from an initial appraisal, REA is also well suited in situations where the large size of a reef study area, complex logistics, limited time, and limited funding support severely restrict the total effort that can be expended. An essential role for experienced coral reef scientists involved in coral reef management and conservation is to participate in REA and train others on the basic techniques to accomplish REA.

No standardized or detailed methodology is advocated here for REA, although the following sequence or steps should be considered:

(a) Define with resource managers and users the purpose and objectives of the REA
(b) Define geographic scope, based upon the objectives and constraints
(c) Select REA team and assign responsibilities
(d) Check with government leaders and other potential users–will the REA meet their needs?
(e) Conduct review of literature, maps, and aerial photographs
(f) Conduct interviews with knowledgeable resident resource users (fishermen, village elders, historians, curators, other scientists, etc.)
(g) Select field sites, relying heavily on the above inputs and steps
(h) Schedule and accomplish field work and include contingency plans for unscheduled disruptions
(i) Each participant analyzes results and prepares preliminary technical report for review by REA leadership
(j) Leader(s) prepares preliminary synthesis report and send to other team members and user groups for review and comment
(k) Finalize and submit synthesis report including recommendations
(l) Finalize and publish technical reports
(m) Follow-up with users on subsequent study phases (monitoring, protected area planning, etc.)

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