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Migrations of green turtles in the central South Pacific

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Abstract

Migrations of seven post-nesting green turtles at Rose Atoll (American Samoa) were tracked by satellite transmitters in 1993–1995. Most turtles migrated 1600 km to foraging areas in Fiji and occupied home ranges averaging 27 km^2. Additional tag recaptures from other studies indicate a common pattern of turtle movement in the central South Pacific region. In total, the 26 recaptures of primarily post-nesting turtles from French Polynesia, American Samoa, and Cook Islands showed a similar course of direction and destination: 96% migrated westward after nesting, with 58% going specifically to Fiji. We propose that this pattern reflects the lower availability of turtle food east of Fiji where most islands are small, steep and have limited areas suitable for seagrass or algal growth. In contrast, Fiji's extensive pastures of seagrass and algae appear to be a significant resource for many green turtles in the region. These turtles apparently spend most of their adult life in Fijian waters, taking only brief migrations to other islands to nest.

Keywords: Sea turtle; *Chelonia mydas*; Migration; South Pacific; American Samoa; Fiji

1. Introduction

Most stocks of the green turtle *Chelonia mydas* in the United States-affiliated Pacific islands (except Hawaii) have seriously declined and should probably be classified as 'endangered' rather than 'threatened' under the Endangered Species Act (National Marine Fisheries Service and United States Fish and Wildlife Service, 1998). The World Conservation Union similarly lists the global population of green turtles as 'endangered' (Seminoff, 2002). The major threats to these stocks are human harvests of turtles and eggs, both within areas of US jurisdiction and on shared stocks when they migrate outside US jurisdiction. To protect these stocks, it is essential to determine where they migrate during different stages of their life cycle.

Green turtles often migrate great distances between nesting and feeding areas (summarized by Hirth, 1993, 1997), but such information in the South Pacific is rudimentary because the region is geographically large and contains thousands of islands. Available data indicate extensive migrations across the South Pacific (South Pacific Regional Environmental Programme, 1993, 1998). In this paper, we report on the migrations of post-nesting green turtles tagged at Rose Atoll National Wildlife Refuge (American Samoa) and review migration patterns of this species in the central South Pacific region. Rose Atoll (14° 32′ S, 168° 08′ W), is a small, remote coral reef where green turtles have been tagged intermittently for several decades (Balazs, 1996). The turtle population there is small—Tuato'o-Bartley et al. (1993) estimated that there might be 24–36 nesting females there annually. The limited information about green turtles at Rose Atoll, and elsewhere in the Samoan Archipelago, has been reported by: Satchet (1954); Balazs (1982), Witzell (1982); Tuato'o-Bartley et al. (1993); Balazs et al. (1994); Grant et al. (1997); and Utzurrum (2002).

2. Methods

Telonics ST-3 satellite transmitters were deployed on seven nesting green turtles at Rose Atoll during the nesting seasons of 1993–1995 (an eighth tag malfunctioned).

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Average turtle size was 104.4 cm curved carapace length (range 96.5–113 cm). Satellite tags weighed 765 g (<1% of a turtle's approximate weight) and measured 17×10×3.5 cm with the antenna extending 13 cm from the top. Tagging procedures were described by Balazs et al. (1996). Positional data were received and processed by Service Argos. Argos positional accuracies were less than 1 km for about 72% of the positions (accuracy categories LC 1–3) and at least 1 km for about 28% of the positions (LC 0), although an occasional position with no positional accuracy estimate was used if there were multiple days without LC 0–3 data. Data were filtered to eliminate unreasonable swimming speeds or >90° directional changes. Tag duty cycles (hours on/off) were either 6/6 or 3/3.

Migration speed and distance were calculated using the most accurate position (LC 0–3) per day, if available. Speeds were calculated as the number of hours taken to traverse the distance traveled during each near-daily period, and the average of these was used as the overall speed. Total distance traveled was the sum of the distances between each near-daily distance position.

Home ranges were estimated for those turtles that reached a resting/foraging area as determined by a turtle remaining in a general area for over one month. Home ranges were calculated in ArcView GIS (ESRI) using positional data with accuracies of 150–1000 m (LC 1–3). For each turtle, a 1000 m buffer was created around each position (to account for the least accurate position category used) and a polygon was created that encompassed all of the buffered points, then the area of the polygon was determined.

An additional 46 nesting females were tagged opportunistically at Rose Atoll with metal flipper tags during the period 1971–1996 (Balazs, 1996).

Sea surface currents were tracked by surface drifter buoys (0.5 m diameter), each equipped with a satellite transmitter and attached to a large windsock-like drogue about 15 m below the surface (manufactured by Technocean). Six drifter buoys were deployed throughout American Samoa by the NOAA ship *Townsend Cromwell* in February 2002 and were tracked up to 14 months by Service Argos. The net speed of each drifter was determined once the drifter left the Samoan Archipelago and exhibited directional westerly movement. Net speed was calculated as the total time elapsed for a drifter to cross the 670 km distance between longitudes 173 W and 179 W. Potential impacts of El Nino conditions on surface conditions were not addressed.

3. Results

The seven satellite-tagged green turtles remained at or near Rose Atoll for approximately 2 months before departing to foraging grounds in late December to January (Table 1). Six of the seven then migrated westward to Fiji, the seventh traveled in nearly the opposite direction to French Polynesia near Raiatea (Fig. 1). On average, these turtles traveled 1600 km at a rate of 1.8 km/hr and were 40 days in transit (Table 1).

Once in Fiji, five of the satellite tags continued transmitting for 1.3–3.5 months thus providing information about the turtles' local movements on their feeding grounds. During this period (February–April), each turtle took up residence in a different part of Fiji (Fig. 2) and occupied a relatively small home range averaging 27 km^2 in size (Table 1).

There have been only three recaptures of the 46 flipper-tagged adult females from Rose Atoll that had been tagged in 1971–1996: two in Fiji (both were taken for food) and one found dead in Vanuatu.

Altogether, 9 of the 10 recoveries (satellite-tags and flipper-tags combined) migrated westward after nesting, and 8 of the 10 went to Fiji. While their means of navigation was not investigated, their migration routes closely paralleled ocean surface currents, albeit measured 7–9 years later. All six ocean drifter buoys released in the territory in 2002 traveled towards Fiji at a net rate of 0.54 km/h (range 0.40–0.65 km/h) after spending 1–10 months drifting around the Samoan Islands (Fig. 3).

4. Discussion

The extensive migrations recorded in this study are similar to those obtained for post-nesting green turtles elsewhere in the world. Satellite telemetry has demonstrated that green turtles often travel open-ocean distances of 1000–2000 km between their nesting and foraging areas (summarized in Hirth, 1997; also see Luschi et al., 1998; Cheng, 2000; Bali et al., in press).

The migrations of green turtles from Rose Atoll, when coupled with other data from the region, indicate a common pattern of turtle movement in the central South Pacific region (Table 2). Altogether, 570 adult green turtles have been tagged in the region during the period 1972–2000 (557 nesting females and 13 adult males at the nesting grounds). Most were flipper-tagged at Scilly Atoll in 1972–1984 ($n=461$) and 1991 ($n=52$), and were recovered in Fiji (6 turtles), Vanuatu (3), New Caledonia (2) Wallis Island (1), Tonga (1) and Cook Islands (1) (Balazs et al., 1995). Another flipper-tagged green turtle was released in Rangiroa, French Polynesia and recovered in the Solomon Islands (South Pacific Regional Environmental Programme, 1993). Finally, a green turtle was satellite-tagged in the Cook Islands and recovered in Fiji (Balazs, unpublished data). Average tag "recovery" rates have been 89% for satellite tags ($n=9$) and 3% for metal flipper tags ($n=561$), although the recovery rate for flipper tags is probably lower due

Table 1
Tag and migration data for post-nesting green turtles at Rose Atoll, American Samoa

Satellite tag no.	Tagging date	Size ccl[a] (cm)	Days before departure	Days in transit	Speed (km/h)	Distance (km)	Endpoint	Days after arrival[b]	Home range (km^2)
4807	4 November 1993	100.0	73	37	1.7	1475	Fiji, Lau Group	58	20
4808	3 November 1993	107.0	48	30	2.0	1450	Fiji, Vanua Levu	66	19
4809	3 November 1993	96.5	54	44	1.7	1750	Fiji, Vanua Levu	[c]	–
4805	27 October 1994	100.0	93	53	2.2	1759	French Polynesia	[d]	–
25692	23 October 1995	113.0	60	31	1.8	1349	Fiji, Taveuni	120	37
25693	24 October 1995	104.5	72	35	1.8	1558	Fiji, Vanua Levu	62	48
25694	26 October 1995	109.5	75	50	1.5	1849	Fiji, Viti Levu	41	12
	Averages:	104.4	68	40	1.8	1599		69	27

[a] Curved carapace length.
[b] Days after arrival before transmissions stopped.
[c] Turtle was apparently captured.
[d] Transmissions stopped before turtle reached foraging site.

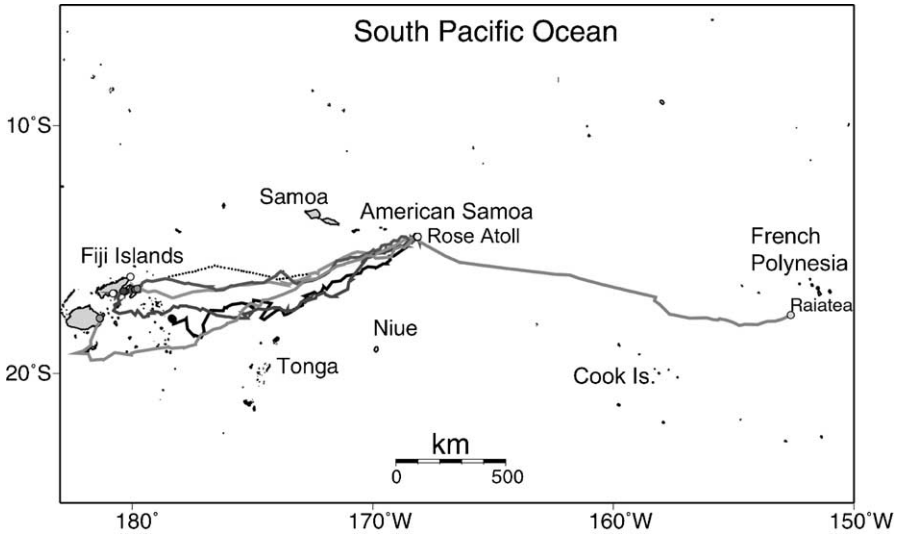

Fig. 1. Migration routes of seven green turtles after departing nesting grounds at Rose Atoll National Wildlife Refuge (American Samoa).

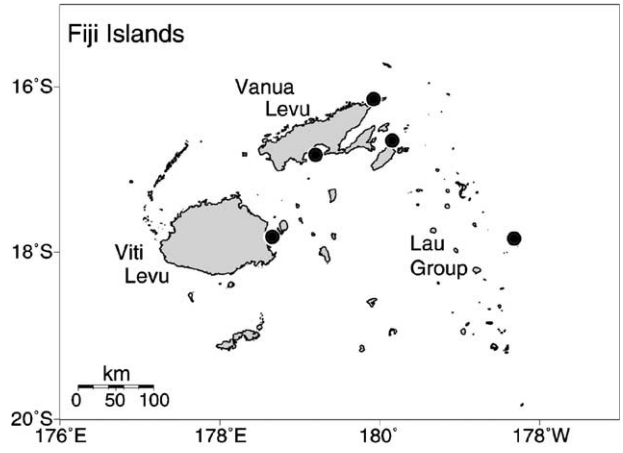

Fig. 2. Home range locations of five green turtles (black dots) in resident foraging pastures in Fiji following their post-nesting migration from Rose Atoll in American Samoa. Actual home range sizes were approximately one tenth the size of the black dots shown in this figure.

to unreported tag releases in the region. To date, 26 turtles have been recaptured and their migrations were similar in both direction and destination: 96% traveled westward after the nesting period with 58% going specifically to Fiji (Table 2).

A plausible explanation for this pattern is that, after nesting, the turtles migrate westward to better feeding opportunities. The rationale for this hypothesis is that, in the central South Pacific, large areas of shallow water habitat required for expansive growths of seagrass and algae that are eaten by the turtles become less common as one proceeds eastward from Fiji. A sharp demarcation line occurs between Fiji and Samoa where the submarine Tongan Trench separates two of the Earth's tectonic plates, the Pacific Plate and Indo-Australian Plate. To the east of the trench, the Pacific Plate can be characterized as a deep (4–5 km) seafloor punctuated by a relatively low number of small, steeply sloping islands.

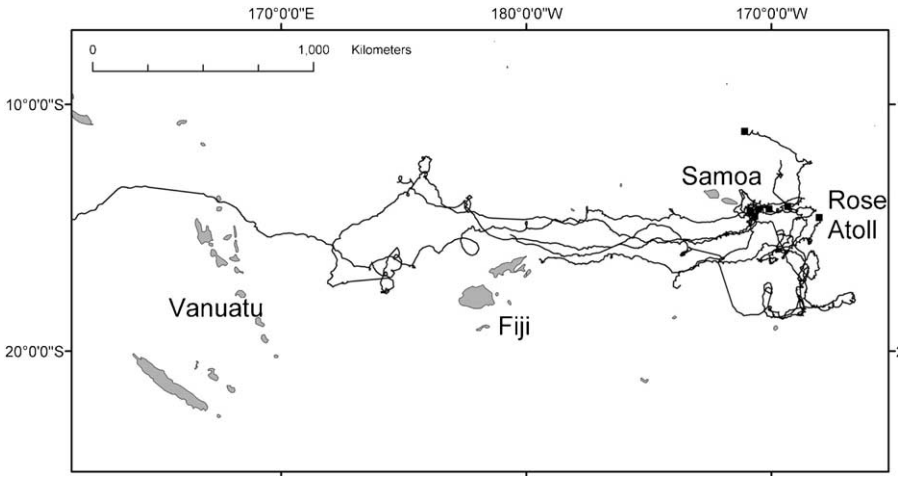

Fig. 3. Tracks of six drifter buoys released at various locations in the Territory of American Samoa, February 2002. After varying months spent drifting around the Samoan Islands, the drifters travelled westward towards Fiji and beyond.

Table 2
Recaptures of 23 post-nesting and three adult male green turtles in the central South Pacific region

Tag site	Turtles tagged[a]	Recaptured			Reference
		Total	To west	To Fiji	
Rose Atoll, American Samoa	55	10	9	8	This study
Scilly Atoll, French Polynesia	513[b]	14	14	6[c]	Balazs et al. (1995)
Rangiroa, French Polynesia	1	1	1	0	South Pacific Regional Environment Programme (1993)
Palmerston Atoll, Cook Islands	1	1	1	1	Balazs, unpublished data
Total	570	26	25 (96%)	15 (58%)	

[a] Includes both satellite and flipper tags.
[b] Includes 13 adult males.
[c] Includes three adult males.

To the west of the trench, the Indo-Australian Plate is generally less deep and has more and larger islands with considerable areas of shallow-water habitat suitable for seagrass and algal growth. As an illustration of this difference, the combined land masses of the small islands east of the Tongan Trench (7448 km^2) amount to less than half that occurring in the Fiji Islands alone (18,272 km^2), and only 15% of the combined islands of Fiji, Vanuatu, and New Caledonia (49,565 km^2) (South Pacific Commission, 1995).

Adding to this geographical difference in suitable habitat is the well-known decrease in species diversity as one proceeds from the Indo-Pacific region eastward into the Pacific Ocean (e.g., Randall, 1998). Seagrass diversity, in particular, declines from 14 species in the western Indo-Pacific region to only two species in French Polynesia (Mukai, 1993; Coles and Lee Long, 1999; Payri et al., 2000). While this does not automatically imply that seagrass biomass declines as well, we are not aware of any significant concentrations of seagrass east of Fiji in the central South Pacific. In contrast, Fiji has extensive pastures of seagrass (Pritchard, 1982; Hirth, 1971 cited in Guinea, 1993), and Hirth (1997) noted the close relationship between the distributions of green turtles and seagrasses in his review of *Chelonia mydas*.

We recognize that this hypothesis may be an oversimplification for several reasons. (1) It is likely that additional islands west of Fiji, such as Vanuatu and New Caledonia, are also important foraging areas for turtles from central Pacific islands. (2) Green turtles also eat certain marine algae, sometimes exclusively, but the distribution of algal biomass in the region is not known; however, algae also require shallow waters and thus may be similarly less abundant east of Fiji. (3) Not all green turtles vacate eastern areas—some juveniles, for example, reside year-round in the Samoan Archipelago (Witzell, 1982; Grant et al., 1997) and thus must be able to find food there.

Despite these caveats, the hypothesis is best considered as a population response to gain access to sufficient food resources so that the turtles can recover from migrating great distances to and from nesting beaches and also obtain additional food reserves so that they can reproduce again at a later date. That this reproductive recovery

may take 4–5 years to accomplish (based on the internesting interval of green turtles in Australia—Limpus, 1993; Limpus et al., 1993) emphasizes the need to go where food resources are greatest. This lengthy internesting interval would also indicate that the Rose Atoll turtles spend most of their adult life in Fiji. For example, if we estimate (from the satellite tagging data) that a round-trip migration to nest at Rose Atoll takes approximately 5 months, and that a trip occurs once every 4 years on average, then fully 90% of the turtles' adult life would be spent in Fijian waters.

Consequently, the seagrass and algae beds of Fiji should be viewed as a regionally significant resource for many of the green turtles in the central South Pacific. These foraging areas are vital to the reproductive success of turtles that nest in many other island nations in the region, and the need to protect such areas is a critical part of sea turtle conservation (Bjorndal, 1999; Gibson and Smith, 1999).

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References

Balazs, G., 1982. Status of sea turtles in the central Pacific Ocean. In: Bjorndal, K. (Ed.), Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, DC, pp. 243–252.

Balazs, G., 1996. Historical summary of sea turtle observations at Rose Atoll, American Samoa, 1839–1993. National Marine Fisheries Service, Honolulu Laboratory, Hawaii (Unpublished report).

Balazs, G., Craig, P., Winton, B., Miya, R., 1994. Satellite telemetry of green turtles nesting at French Frigate Shoals, Hawaii, and Rose Atoll, American Samoa. In: Bjorndal, K., Bolten, A., Johnson, D. (Comps.), Proceedings 14th Annual Symposium on Sea Turtle Biology and Conservation, National Atmospheric and Oceanic Administration Tech. Memo. NMFS-SEFSC-351, pp. 184–187.

Balazs, G., Siu, P., Landret, J-P., 1995. Ecological aspects of green turtles nesting at Scilly Atoll in French Polynesia. In: Richardson, J., Richardson, T. (Eds.), Proceedings 12th Annual Workshop on Sea Turtle Biology and Conservation, 1992, National Atmospheric and Oceanic Administration Tech. Memo. NMFS-SEFSC-361, pp. 7–10.

Balazs, G., Miya, R., Beavers, S., 1996. Procedures to attach a satellite transmitter to the carapace of an adult green turtle, *Chelonia mydas*. In: Keinath, J., Barnard, D., Musick, J., Bell, B. (Comps.), Proceedings of the 15th Annual Symposium on Sea Turtle Biology and Conservation, 1995. National Atmospheric and Oceanic Administration Tech. Memo. NMFS-SEFSC-367, pp. 21–26.

Bali, J., Liew, H-C., Chan, E-H., Tisen, O. Long distance migration of green turtles from the Sarawak Turtle Islands, Malaysia. NOAA Tech. Memo. (in press).

Bjorndal, K., 1999. Priorities for research in foraging habitats. In: Eckert, K., Bjorndal, K., Abreu-Grobois, F., Donnelly, M. (Eds.), Research and Management Techniques for Conservation of Sea Turtles. IUCN/SSC Marine Turtle Specialist Group, Pub. 4, pp. 12–14.

Cheng, I.-J., 2000. Post-nesting migrations of green turtles (*Chelonia mydas*) at Wan-An Island, Penghu Archipelago, Taiwan. Marine Biology 137, 747–754.

Coles, R., Lee Long, W., 1999. Seagrasses. In: Eldredge, L., Maragos, J., Holthus, P., Takeuchi, H. (Eds.), Marine and Coastal Biodiversity in the Tropical Island Pacific Region. Vol. 2. Pacific Science Assoc, Honolulu, Hawaii, pp. 21–46.

Gibson, J., Smith, G., 1999. Reducing threats to foraging habitats. In: Eckert, K., Bjorndal, K., Abreu-Grobois, F., Donnelly, M. (Eds.), Research and Management Techniques for Conservation of Sea Turtles. IUCN/SSC Marine Turtle Specialist Group, Pub. 4, pp. 184–188.

Grant, G., Craig, P., Balazs, G., 1997. Notes on juvenile hawksbill and green turtles in American Samoa. Pac. Sci. 51, 48–53.

Guinea, M. 1993. The sea turtles of Fiji. South Pacific Regional Environment Programme. Reports and Studies No. 65.

Hirth, H., 1971. South Pacific Islands—marine turtle resources. Food and Agriculture Organization, United Nations, Rome.

Hirth, H., 1993. Marine turtles. In: Wright, A., Hill, L. (Eds.), Nearshore Marine Resources of the South Pacific, Inst. Pacific Studies (Fiji), Forum Fisheries Agency (Honiara). International Centre for Ocean Development, Canada, pp. 329–370.

Hirth, H., 1997. Synopsis of the biological data on the green turtle *Chelonia mydas* (Linnaeus 1758). US Fish and Wildlife Service, Biological Report 97(1).

Limpus, C., 1993. The green turtle, *Chelonia mydas*, in Queensland: breeding males in the southern Great Barrier Reef. Wildl. Res. 20, 513–523.

Limpus, C., Miller, J., Parmenter, C., 1993. The northern Great Barrier Reef green turtle *Chelonia mydas* breeding population. In: Zevering, K., Zevering, C. (Eds.), Raine Island and Environs Great Barrier Reef: Quest to Preserve a Fragile Outpost of Nature. Raine Island Corp. and Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia, pp. 47–50.

Luschi, P., Hays, G., Del Seppia, C., Marsh, R., Papi, F., 1998. The navigational feats of green sea turtles migrating from Ascension Island investigated by satellite telemetry. Proc. Royal Soc. Lond. B 265, 2279–2284.

Mukai, H., 1993. Biogeography of the tropical seagrasses in the western Pacific. Aust. J. Mar. Freshwater Res. 44, 1–17.

National Marine Fisheries Service, United States Fish and Wildlife Service, 1998. Recovery plan for the US Pacific populations of the green turtles (*Chelonia mydas*). National Marine Fisheries Service, Silver Spring, MD.

Payri, C., de R. N'yeurt, A., Orempuller, J., 2000. Algae of French Polynesia. Au Vent Des Iles, Tahiti.

Pritchard, P., 1982. Marine turtles of the South Pacific. In: Bjorndal, K. (Ed.), Biology and Conservation of Sea Turtles. Smithsonian Institution Press, Washington, DC, pp. 253–262.

Randall, J., 1998. Zoogeography of shore fishes of the Indo-Pacific region. Zoological Studies 37, 227–268.

Satchet, M., 1954. A summary of information on Rose Atoll. Atoll Research Bulletin 29, 1–25.

Seminoff, J., 2002. Global status of the green turtle (*Chelonia mydas*): a summary of the 2001 status assessment for the IUCN Red List Programme. In: Kinan, I. (Ed.), Proceedings of the Western Pacific Sea Turtle Cooperative Research & Management Workshop. Western Pacific Regional Fishery Management Council, Honolulu, pp. 197–211.

South Pacific Commission, 1995. South Pacific Economies Pocket Statistical Summary. Noumea Cedex, New Caledonia.

South Pacific Regional Environmental Programme. 1993. Report of the 3rd Meeting of the Regional Marine Turtle Conservation Programme. Apia, Samoa.

South Pacific Regional Environmental Programme. 1998. Regional marine turtle conservation programme turtle tagging database report, 1997 & 1998. Apia, Samoa.

Tuato'o-Bartley, N., Morrell, T., Craig, P., 1993. The status of sea turtles in American Samoa in 1991. Pacific Science 47, 215–221.

Utzurrum, R., 2002. Sea turtle conservation in American Samoa. In: Kinan, I. (Ed.), Proceedings of the Western Pacific Sea Turtle Cooperative Research & Management Workshop. Western Pacific Regional Fishery Management Council, Honolulu, pp. 33–36.

Witzell, W., 1982. Observations on the green sea turtle (*Chelonia mydas*) in Western Samoa. Copeia 1982, 183–185.