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Article *in* Pacific Science · October 2010

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Impacts of Recreational Divers on Palauan Coral Reefs and Options for Management[1]

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Abstract: Recent growth in the popularity of recreational scuba diving has generated concerns about resulting impacts to coral reefs, particularly in locations such as the Republic of Palau, a world-renowned dive destination with rapidly increasing numbers of visitors. Divers were observed in-water at three of the most visited dive sites in the Rock Islands–Southern Lagoon Area: German Channel, Ngerchong, and Big Drop-off. Dive guides were interviewed about diver impacts at German Channel and Ngerchong. Divers' contact rates with hard coral ranged from 0.87 ± 0.27 to 2.98 ± 0.59 contacts diver^{-1} 10 min^{-1} (mean $\pm$ SEM). Three instances of obvious physical damage were observed. Holding and fin contacts were the most common potentially damaging behaviors of divers, particularly those with cameras or gloves. Guides identified natural impacts (63% of respondents) and divers (34% of respondents) as the primary causes of damage to coral. Proactive management is essential to mitigate any negative impacts of recreational diving on coral reefs and to ensure resilience against other increasing threats. Long-term monitoring of dive sites, controls on the use of gloves and underwater photography, and training of guides are suggested to minimize damage caused by divers to coral reefs in Palau and elsewhere.

Dive tourism is a major recreational activity worldwide (Buckley 2004), but this popularity has caused concern due to the potential of physical damage to reefs from anchoring, trampling, kicking, and breaking of corals by divers and tour boats. Although tourism is often perceived as a low-impact alternative for coastal management, a number of studies have confirmed that coral reefs and other sensitive substrates in the Red Sea, the Caribbean, Australia, the Mediterranean, and Africa have been negatively affected by intensive recreational diving pressure (e.g., Rouphael and Inglis 2001, Walters and Samways 2001, Zakai and Chadwick-Furman 2002, Barker and Roberts 2004, Di Franco et al. 2009), and the transition from pristine to "diver-damaged" reef can occur very quickly where dive tourism is allowed to grow in an unregulated manner (Hawkins and Roberts 1992). Divers may also be less willing to pay a conservation access fee as the quality of a dive site declines in terms of visibility, species diversity, and coral cover (Parsons and Thur 2008). The continued growth of recreational diving is thus a threat to both the ecological and economic sustainability of reefs (Davis and Tisdell 1995) and should be considered in the planning of effective marine resource management strategies. Considering that coral reefs are seriously threatened worldwide, primarily from the consequences of climate change (Hughes et al. 2003, Hoegh-Guldberg et al. 2007), urgent action is necessary to reduce the effects of controllable impacts, such as those associated with recreational divers.

[1] Funding for this work was generously provided by the U.S. National Fish and Wildlife Foundation and Koror State Government. Manuscript accepted 31 December 2009.

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Pacific Science (2010), vol. 64, no. 4:557–565
doi: 10.2984/64.4.557

The coral reefs of the Republic of Palau (07° 30′ N, 134° 30′ E) (Figure 1) are among the most biologically diverse in the Indo-Pacific (Maragos and Cook 1995) and consistently rate as one of the world's best diving locations (e.g., Halls 2008). Following a rapid increase from only 4,000 visitors per annum during the 1980s (Graham et al. 2001), tourism is now the largest income source for the nation's private sector. In 2002, $66.1 million were generated from the estimated 58,560 visitors (Palau Visitors Authority 2003), 70% of whom were divers (Osman 2003), and Koror State collected approximately $505,000 from Rock Island permit fees alone (Koror State Government 2004). The Palauan tourism sector has continued to expand, generating $111.9 million (U.S. Department of State–Bureau of East Asian and Pacific Affairs 2009) from 88,175 visitors (Palau Visitors Authority 2008) in 2007. As an island nation, Palauan people have strong traditional ties to the sea and are aware that this rapid development carries with it substantial ecological costs and impacts on marine resource–based livelihoods with a potential for conflict between tourism and artisanal fishing activities (Ueki 2000, Matthews 2004). It has also been demonstrated that the amount of live coral cover directly affects divers' satisfaction in Palau and consequently the potential revenue from recreational diving (Graham et al. 2001).

The unique natural resources of the Rock Islands–Southern Lagoon Area (Figure 1), where most of Palau's 75 dive sites are located, are formally managed by Koror State Department of Conservation and Law Enforcement. However, as dive tourism has developed, congestion has become an issue at some dive sites, a concern that is compounded by a lack of empirical data on which to establish a standard for diver impact on that area (Ueki 2000). In 2004, the Rock Islands–Southern Lagoon Area Management Plan was adopted (Koror State Government 2004), which identified "damage to reef habitat from divers and snorkelers touching and standing on corals or removing corals or invertebrates" as a primary concern associated with tourism and recreational activities. Thus, one of the proposed actions of the management plan was to "regulate diving and snorkeling activities in the Management Area to reduce site congestion and damage to corals and increase site safety." Such proactive management of dive sites is clearly essential to cope with the continued increase in visitation and to ensure that both economic and recreational needs are met. In this study, we employed *in situ* observation and self-administered questionnaire surveys of dive guides to evaluate actual occurrence and perceptions of diver damage to coral reefs to generate effective, stakeholder-inclusive management recommendations for recreational diving on coral reefs.

MATERIALS AND METHODS

This study was conducted at three dive sites in 2003 (before the Rock Islands–Southern Lagoon Area Management Plan was put into action) within the Rock Islands–Southern Lagoon Area: German Channel, Ngerchong, and Big Drop-off (Figure 1). These sites were selected by Koror State Department of Conservation and Law Enforcement based on a lack of biological data, popularity with recreational divers, and the need for improved management practices. All of these sites have been ranked within the top 20 dive sites in Palau; German Channel and Big Drop-off are visited by almost every dive tourist and are in the top seven (Palau Conservation Society 2001). Ngerchong was a popular site before the 1997/1998 coral-bleaching event and, given its sheltered aspect, is primarily dived in rough weather (A. Eledui, pers. comm., 2002). Most dives at German Channel are conducted along the seaward side of the opening of the channel, and the reef slopes to a sandy bottom at around 25 m; Ngerchong is a sloping reef with a maximum depth of 15 m, and Big Drop-off is a vertical wall that starts at 1 m and drops steeply to around 600 m.

Diver impacts were quantified using in-water observation techniques based on Rouphael and Inglis (1995). Daily selection of sites depended on the choices of dive operators according to weather and sea conditions,

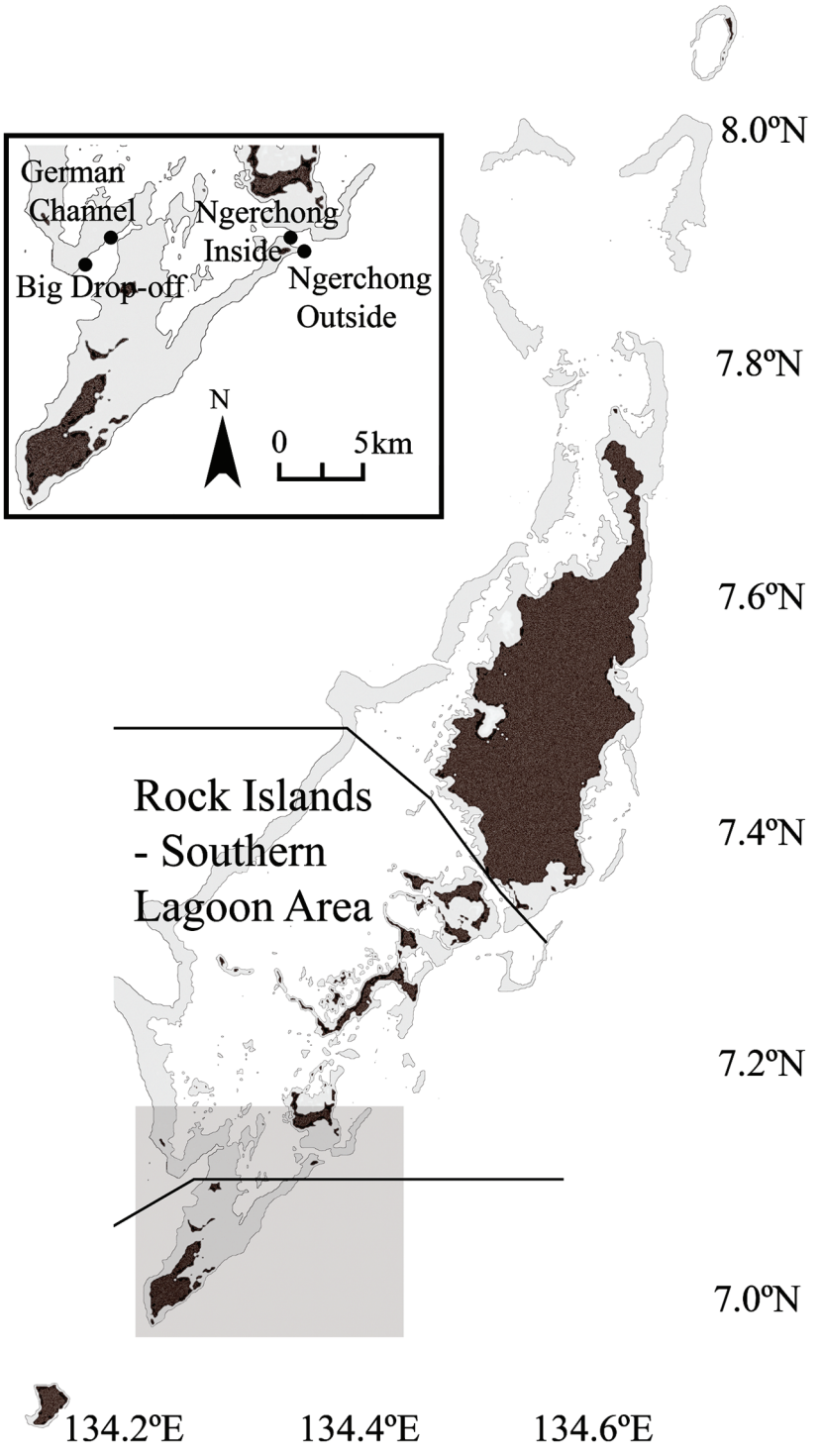

FIGURE 1. Palau, showing location of study sites in the Rock Islands–Southern Lagoon Area.

and individual subjects were selected at random. Two underwater observers independently recorded the behavior of 124 divers (52 divers at German Channel, 35 at Ngerchong, and 37 at Big Drop-off). Each subject was observed for 10 min, and the following details were recorded: number of contacts with the substratum; type of substratum contacted; nature of the contact (e.g., fin contacts, holding); contact obviously damaging (visible breakage) or nondamaging to substratum; type and size of substratum damaged and additional notes on diver accessories (e.g., gloves, cameras). Each observer followed a group of two to four subjects, dependent on group size and intragroup distance, and remained approximately 5 m behind the subjects. Divers generally remained close to other members of their party and did not appear to notice the observation process; data were disregarded for the few cases where the subject appeared to be aware of the observer. Student's *t*-tests were employed to compare contact rates of divers using gloves and cameras with those without.

Dive guides' perceptions of environmental impacts at German Channel and Ngerchong were determined through self-administered questionnaire surveys. Information was recorded on perceived status and impacts to coral reefs and dive site usage. Questionnaires in Japanese and English were distributed to all marine tour operators in Koror. Eighteen companies of the 25 registered water-sports operators in Palau participated in the study, and 35 questionnaires were completed.

RESULTS

At German Channel, divers made contact with hard coral most often of all substrata and sites and also knelt or rested fins on the sand at some point during the dive, usually while waiting for manta rays; interactions with soft corals and sea fans were rare (Table 1). Most interactions involved holding or kicking coral with fins (Table 2), but divers were also observed dragging gauges or *octopus* regulators over the substrata and kneeling indiscriminately on corals, often to take photographs.

At Ngerchong, hard coral was again the most commonly contacted substratum (Table 1), the number of interactions with sand was similar to that for German Channel, and there were no interactions with soft corals

TABLE 1

Diver Contact Rates (mean ± SEM) for Each Substratum at Each Study Site

	Contact Rates Diver^{-1} 10 min^{-1}					
Study Site	Hard Coral	Sand	Rock	Soft Coral	Sea Fan	Other
German Channel	2.98 ± 0.59	1.62 ± 0.26	0.79 ± 0.26	0.19 ± 0.07	0.04 ± 0.03	0.79 ± 0.24
Ngerchong	1.86 ± 0.39	1.23 ± 0.38	0.54 ± 0.20	0	0.03 ± 0.03	0.20 ± 0.09
Big Drop-off	0.87 ± 0.27	0	0.95 ± 0.27	0.08 ± 0.05	0	0

TABLE 2

Diver Contact Rates (mean ± SEM) with Hard Coral for Each Type of Contact at Each Study Site

	Contact Rates Diver^{-1} 10 min^{-1}				
Study Site	Holding	Fins	Gauge	Kneeling	Tank
German Channel	1.25 ± 0.29	0.98 ± 0.26	0.38 ± 0.11	0.31 ± 0.12	0.06 ± 0.04
Ngerchong	0.66 ± 0.22	0.83 ± 0.25	0.20 ± 0.11	0.14 ± 0.12	0.03 ± 0.03
Big Drop-off	0.43 ± 0.16	0.43 ± 0.14	0	0	0

and few with sea fans. As at other sites, most interactions involved kicking coral with fins or holding (Table 2), and there were also instances of divers bumping into corals with their air cylinders as a result of problems with buoyancy control.

Interactions at Big Drop-off differed from those at other sites in that rock was the most commonly contacted substratum and hard coral was less frequently affected (Table 1). There was no sand at Big Drop-off within the depth range usually dived, therefore no interactions were recorded. Interactions with soft coral were rare, and no contacts with sea fans were observed. Of the interactions with coral, half involved divers touching or kicking coral with their fins and the other half involved divers holding coral (Table 2). Half of the interactions with rock also involved touching or kicking with fins; the majority of other interactions involved holding, although there were also cases of divers kneeling on and hitting rocks with their air cylinders.

If data from all sites are combined (all figures given as mean $\pm$ SEM), divers wearing gloves touched hard coral more often (4.1 ± 0.6 interactions diver^{-1} 10 min^{-1}) than those not wearing gloves (1.3 ± 0.3 interactions diver^{-1} 10 min^{-1}) ($t = 3.88$, df $= 44$, $P \leq .0005$), and divers using cameras touched hard coral more often (3.1 ± 0.7 interactions diver^{-1} 10 min^{-1}) than those not using cameras (1.8 ± 0.3 interactions diver^{-1} 10 min^{-1}), but the difference was not found to be significant ($t = 1.70$, df $= 34$, $P \leq .1$). Only three instances of obvious physical damage caused by two divers were recorded during the course of this study, out of a total of 124 divers observed. One interaction involved a diver scraping an air cylinder against a coral head at German Channel, and the other occurred at Big Drop-off, where a diver kicked and broke off two pieces of a branching hard coral.

From the questionnaire survey, dive guides reported hard coral damage at both German Channel and Ngerchong (62% and 71% of respondents, respectively), mainly due to natural causes (63% of respondents), and 71% were aware of coral-bleaching phenomena. Other factors mentioned included diver impact (34% of respondents), anchor damage (23% of respondents), trash (3% of respondents), and triggerfishes (3% of respondents). Kicking ("sometimes" observed by 58% of respondents) and holding ("sometimes" observed by 48% of respondents) coral were thought to be the greatest impacts of divers at German Channel. At Ngerchong, kicking coral was again the most commonly identified impact ("sometimes" observed by 55% of respondents). In general, guides "rarely" saw coral being broken (71% of respondents at German Channel and 68% of respondents at Ngerchong).

Guides (66% of respondents) expressed concern about boat and diver congestion at German Channel, and several made comments about boats speeding through the diving area and causing a hazard to both divers and manta rays. Guides generally felt that there were sufficient mooring buoys at the dive sites (71% of respondents at German Channel, 68% of respondents at Ngerchong) and reported that most or all operators used them at German Channel (94% of respondents) and at Ngerchong (97% of respondents). It was noted that both sites were visited by divers throughout the year, but there were noticeable peaks of usage during January–March at German Channel and during June–August at Ngerchong. Guides reported that they usually saw two or three other dive boats while they were visiting either site.

DISCUSSION

Based on a conservative estimate that 70% of tourists in Palau in 2007 were divers, as in 2002 (61,723), and that 80% of these divers (49,378) conducted a 40-min dive at German Channel, extrapolation of the results generated by this study demonstrates that this density of recreational divers may be responsible for $589{,}000 \pm 117{,}000$ coral contacts and approximately 400 coral breakages annually. This level of impact could clearly have a long-term effect on coral health at the site, and these visitation rates far exceed the 4,000–6,000 (Dixon et al. 1993, Hawkins and Roberts 1994) or 7,000 (Schleyer and

Tomalin 2000) dives per year per site considered to be a reliable rule of thumb to estimate carrying capacity for scuba divers, depending on the biophysical characteristics of the site (West 2001). Although occasional contacts are unlikely to cause permanent damage to corals, cumulative effects in conjunction with other stressors may be more serious (Hawkins et al. 1999, Plathong et al. 2000, Zakai and Chadwick-Furman 2002). Isolated breakages are unlikely to result in the death of a large coral colony because corals can regenerate tissue over small injuries (Hall 2001, Rouphael and Inglis 2002), although small coral colonies take longer to regenerate and may be completely killed by physical damage alone (Kramarsky-Winter and Loya 2000, Oren et al. 2001).

Most studies of diver behavior have concluded that fin kicks were the most prevalent type of contact (e.g., Medio et al. 1997, Rouphael and Inglis 1997) as in this study, where divers often appeared unaware that they had even touched the reef. Divers were also observed intentionally holding onto coral to steady themselves in a current or to get closer to the substratum to see something or take photographs. Divers wearing gloves made contact with hard coral more often as previously noted (e.g., Medio et al. 1997, Schleyer and Tomalin 2000, Walters and Samways 2001). Bans on the use of gloves have been successfully enforced in a number of Marine Protected Areas globally and may also be a useful mitigation measure in the Rock Islands–Southern Lagoon Area.

All guides were observed deliberately keeping away from the substratum, although few paid attention to coral contacts by their clients because the guide tended to remain at the front of the group, looking ahead. Guides' perceptions that coral damage was a result of natural events are supported by the absence of fresh breaks, typical of diver damage, and the obvious presence of rubble resulting from the coral-bleaching event in 1998 (Community Centered Conservation 2003), particularly on the outer, exposed reefs of Palau (Bruno et al. 2001, Golbuu et al. 2007). Kicking and holding onto corals were the most common diver impacts according to guides as supported by in-water observations. Dive guides' briefings (Medio et al. 1997) and close underwater supervision (Barker and Roberts 2004) have been shown to reduce coral damage caused by groups of divers. Effective training of dive guides, through means such as the recently introduced, compulsory Marine Tour Guide Certification Programme (Davis and Kearns 2005), and associated legislation are pragmatic tools to address these issues.

Overcrowding at dive sites, one of the main concerns voiced by dive guides, reduces the "wilderness experience" (Davis and Tisdell 1995, Musa 2002), with impact on enjoyment being significantly correlated with group size (Barker 2003). It has also been demonstrated that sites with human-made structures such as buoys are much less appealing to divers (Inglis et al. 1999), which is perhaps the reason that guides generally believed that installation of further buoys was not an acceptable solution to overcrowding. However, committed use of mooring buoys, as evident in this study, has been shown to effectively mitigate anchor damage to coral reefs (Jameson et al. 2007). Introduction of limits for diver numbers within the Rock Islands–Southern Lagoon Area may not be completely effective in limiting diver damage to coral reefs; there is substantial literature from terrestrial research that suggests that a single, objectively estimated level of use to maintain resource condition is unrealistic (e.g., McCool and Lime 2001, Farrell and Marion 2002). As demonstrated by this work and previous studies, diver behavior, in-water activities, and the biophysical characteristics of the reef will substantially affect the level of impact. In addition, the resilience of coral reefs can vary substantially, even within the same Marine Protected Area (Done 1992, Hughes and Connell 1999).

Long-term monitoring of coral damage and visitation rates to a representative sample of dive sites is one means to effectively assess diver impact and introduce regulations as necessary. Monitoring should primarily focus on early and easily identifiable symptoms of coral community decline, including increases in coral injuries such as broken branch tips

and tissue abrasions (Rouphael and Inglis 1995, Nelson and Mapstone 1998). These site-specific data would be useful for wider, ecoregional spatial planning and zoning strategies (e.g., in Palau: Hinchley et al. 2007) and a definition of limits of acceptable change (Roman et al. 2007). This approach would ensure that controllable impacts on coral reefs such as diver damage are minimized and could capitalize on site-specific resilience to natural impacts such as coral bleaching and ocean acidification, which are predicted to increase considerably in the near future (Hughes et al. 2003, Hoegh-Guldberg et al. 2007). Although protected area managers are often required to balance the apparently conflicting objectives of tourism promotion and natural resource protection, regulations imposed by the Rock Islands–Southern Lagoon Area Management Plan, including a permit system for tourists visiting the area and zoning (Koror State Government 2004), are a major step forward to monitoring and ultimately controlling recreational diver impacts on coral reefs in Palau.

ACKNOWLEDGMENTS

Thanks are due to the Koror State Department for Conservation and Law Enforcement, particularly Adalbert Eledui and Ileb Olkeriil; Rengechel Dlutaoch and Mista Moros; Dr. Kathy Chaston (Coastal Management Officer); Mica Hirose (Japan International Cooperation Agency volunteer); the diver support team: Mike Kearns and Blake McNaughton (U.S. Peace Corps volunteer); Dr Patrick Colin (Coral Reef Research Foundation); and all the marine tour operators and dive guides who participated in this study. We are also grateful to two anonymous reviewers who provided comments on an early draft of the manuscript.

Literature Cited

Barker, N. H. L. 2003. Ecological and socioeconomic impacts of dive and snorkel tourism in St. Lucia, West Indies. Ph.D. thesis, University of York, United Kingdom.

Barker, N. H. L., and C. M. Roberts. 2004. Scuba diver behaviour and the management of diving impacts on coral reefs. Biol. Conserv. 120:481–489.

Bruno, J., C. Siddon, J. Witman, P. Colin, and M. Toscano. 2001. El Niño related coral bleaching in Palau, western Caroline Islands. Coral Reefs 20:127–136.

Buckley, R. 2004. Skilled commercial adventure: The edge of tourism. Pages 37–48 *in* T. V. Singh, ed. New horizons in tourism: Strange experiences and stranger practices. CABI Publishing, Wallingford.

Community Centered Conservation. 2003. Baseline surveys and threat assessment of dive sites in Koror State, Palau: A report submitted to the Department of Conservation and Law Enforcement, Koror State Government. C3 Technical Report Series No. 1. ISSN 1754-5188. Community Centred Conservation (C3), London, United Kingdom.

Davis, D., and C. Tisdell. 1995. Recreational scuba-diving and carrying capacity in marine protected areas. Ocean Coastal Manage. 26:19–40.

Davis, P. Z. R., and C. M. Kearns. 2005. Koror State Government marine tour guide certification manual. Final edits by The Environment, Inc., The Nature Conservancy, Palau Conservation Society, and Koror State Department of Conservation and Law Enforcement and the Coral Reef Research Foundation.

Di Franco, A., M. Milazzo, P. Baiata, A. Tomasello, and R. Chemello. 2009. Scuba diver behaviour and its effects on the biota of a Mediterranean marine protected area. Environ. Conserv. 36:32–40.

Dixon, J. A., L. F. Scura, and T. van't Hof. 1993. Meeting ecological and economic goals: Marine parks in the Caribbean. Ambio 22:117–125.

Done, T. J. 1992. Effects of tropical cyclone waves on ecological and geomorphological structures on the Great Barrier Reef. Cont. Shelf Res. 12:859–872.

Farrell, T. A., and J. L. Marion. 2002. The protected area visitor impact management (PAVIM) framework: A simplified process for making management decisions. J. Sustainable Tourism 10:31–51.

Golbuu, Y., S. Victor, L. Penland, D. Idip Jr., C. Emaurois, K. Okaji, H. Yukihira, A. Iwase, and R. van Woesik. 2007. Palau's coral reefs show differential habitat recovery following the 1998 bleaching event. Coral Reefs 26:319–332.

Graham, T., N. Idechong, and K. Sherwood. 2001. The value of dive-tourism and the impacts of coral bleaching on diving in Palau. Pages 59–71 *in* H. Z. Schuttenburg, ed. Coral bleaching: Causes, consequences and response. Selected papers presented at the 9th International Coral Reef Symposium on Coral Bleaching: Assessing and Linking Ecological and Socioeconomic Impacts, Future Trends and Mitigation Planning. Coastal Management Report 2230. ISBN 1-8854-40-6. Coastal Resources Center, University of Rhode Island, Narragansett.

Hall, V. R. 2001. The response of *Acropora hyacinthus* and *Montipora tuberculosa* to three different types of colony damage: Scraping injury, tissue mortality and breakage. J. Exp. Mar. Biol. Ecol. 264:209–223.

Halls, M. 2008. Dive: The ultimate guide to the world's top dive locations. Firefly Books, Richmond Hill, Ontario, Canada.

Hawkins, J. P., and C. M. Roberts. 1992. Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. Biol. Conserv. 62:171–178.

———. 1994. The growth of coastal tourism in the Red Sea: Present and future effects on coral reefs. Ambio 23:503–508.

Hawkins, J. P., C. M. Roberts, T. van't Hof, K. De Meyer, J. Tratalos, and C. Aldam. 1999. Effects of recreational scuba diving on Caribbean coral and fish communities. Conserv. Biol. 13:888–897.

Hinchley, D., G. Lipsett-Moore, S. Sheppard, F. U. Sengebau, E. Verheij, and S. Austin. 2007. Biodiversity planning for Palau's Protected Areas Network: An ecoregional assessment. TNC Pacific Island Countries Report No. 1/07.

Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, and M. E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science (Washington, D.C.) 318:1737–1742.

Hughes, T. J., and J. H. Connell. 1999. Multiple stressors in coral reefs: A long-term perspective. Limnol. Oceanogr. 44:932–947.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. Science (Washington, D.C.) 301:929–933.

Inglis, G. J., V. Y. Johnson, and F. Ponte. 1999. Crowding norms in marine settings: A case study of snorkeling on the Great Barrier Reef. Environ. Manage. 24:369–381.

Jameson, S. C., M. S. A. Ammar, E. Saadalla, H. M. Mostafa, and B. Riegl. 2007. Diving sites in the Egyptian Red Sea during a period of severe anchor damage: A baseline for restoration and sustainable tourism management. J. Sustainable Tourism 15:309–323.

Koror State Government. 2004. Rock Islands–Southern Lagoon Area management plan 2004–2008. Vol. 1. Management plan. Koror State Government, Republic of Palau.

Kramarsky-Winter, E., and Y. Loya. 2000. Tissue regeneration in the coral *Fungia granulosa:* The effect of extrinsic and intrinsic factors. Mar. Biol. (Berl.) 137:867–873.

Maragos, J. E., and C. W. Cook Jr. 1995. The 1991–1992 rapid ecological assessment of Palau's coral reefs. Coral Reefs 14:237–252.

Matthews, E. 2004. Subsistence fishing activities in the Rock Islands. PCS Report No. 2004-01. Palau Conservation Society, Koror, Palau.

McCool, S. F., and D. W. Lime. 2001. Tourism carrying capacity: Tempting fantasy or useful reality. J. Sustainable Tourism 9:372–388.

Medio, D., R. F. G. Ormond, and M. Pearson. 1997. Effect of briefings on rates of damage to corals by scuba divers. Biol. Conserv. 79:91–95.

Musa, G. 2002. Sipadan: A SCUBA-diving paradise: An analysis of tourism impact, diver satisfaction and tourism management. Tourism Geogr. 4:195–209.

Nelson, V. M., and B. D. Mapstone. 1998. A review of environmental impact monitoring of pontoon installations in the Great Barrier Reef Marine Park. Technical Report No. 13. CRC Reef Research Centre, Townsville.

Oren, U., Y. Benayahu, H. Lubinevsky, and Y. Loya. 2001. Colony integration during regeneration in the stony coral *Favia favus*. Ecology 82:802–813.

Osman, W. M. 2003. Republic of Palau economic report, April 2003. Bank of Hawai'i and East-West Center, Honolulu, Hawai'i.

Palau Conservation Society. 2001. Dive tourism in Palau: Resource use value and management. Palau Conservation Society, Koror, Palau.

Palau Visitors Authority. 2003. 2002–2003 Visitor arrival statistics (http://www.visit-palau.com/admin/newsletter/images/2002~2003_Visitor%20Statistics.pdf).

———. 2008. 2007 and 2008 Visitor arrival statistics (http://www.visit-palau.com/admin/newsletter/images/2007%20to%202008%20Visitor%20Stats.pdf).

Parsons, G. R., and S. M. Thur. 2008. Valuing changes in the quality of coral reef ecosystems: A stated preference study of SCUBA diving in the Bonaire National Marine Park. Environ. Resour. Econ. 40:593–608.

Plathong, S., G. A. Inclis, and M. E. Huber. 2000. Effects of self-guided snorkeling trails on corals in a tropical marine park. Conserv. Biol. 14:1821–1830.

Roman, G. S. J., P. Dearden, and R. Rollins. 2007. Application of zoning and "limits of acceptable change" to manage snorkelling tourism. Environ. Manage. 39:819–830.

Rouphael, T., and G. Inglis. 1995. The effects of qualified recreational scuba divers on coral reefs. Technical Report No. 4. CRC Research Centre, Townsville.

Rouphael, A. B., and G. J. Inglis. 1997. Impacts of recreational scuba diving at sites with different reef topographies. Biol. Conserv. 82:329–336.

———. 2001. Take only photographs and leave only footprints?: An experimental study on the impacts of underwater photographers on coral reef dive sites. Biol. Conserv. 100:281–287.

———. 2002. Increased spatial and temporal variability in coral damage caused by recreational scuba diving. Ecol. Appl. 12:427–440.

Schleyer, M. H., and B. J. Tomalin. 2000. Damage on South African coral reefs and an assessment of their sustainable diving capacity using a fisheries approach. Bull. Mar. Sci. 67:1025–1042.

Ueki, M. F. 2000. Eco-consciousness and development in Palau. Contemp. Pac. 12:481–487.

U.S. Department of State–Bureau of East Asian and Pacific Affairs. 2009. Background note: Palau. August 2009. (http://www.state.gov/r/pa/ei/bgn/1840.htm).

Walters, R. D. M., and M. J. Samways. 2001. Sustainable dive ecotourism on a South African coral reef. Biodivers. Conserv. 10:2167–2179.

West, J. 2001. Environmental determinants of resistance to coral bleaching: Implications for management of Marine Protected Areas. Pages 40–52 *in* R. Salm and S. L. Coles, eds. Coral bleaching and marine protected areas. Proceedings of the Workshop on Mitigating Coral Bleaching Impact through MPA Design, Bishop Museum, Honolulu, Hawai'i, 29–31 May 2001. Asia Pacific Coastal Marine Program Report 0102. The Nature Conservancy, Honolulu, Hawai'i.

Zakai, D., and N. E. Chadwick-Furman. 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. Biol. Conserv. 105:179–187.