PROTECTING GUAM'S CORAL REEFS BY IMPROVING SCUBA DIVER BEHAVIOR: A CORAL-SAFE DIVING REMINDER REDUCES REEF CONTACTS

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Abstract

Coral reefs are a critical resource for the culture and economy of the American territory of Guam, but the island's coral reef resources are increasingly imperiled by climate change, particularly bleaching caused by rising seawater temperatures. Severe bleaching events in 2013, 2014, 2016, and 2017 have caused mass mortality of corals and made evident the critical need to reduce local stressors to protect the future of Guam's reefs. An estimated 300,000 people scuba dive on Guam's reefs annually, but the impacts of these divers are unknown. This study examines the impacts of scuba diving activity on highly trafficked coral reefs and tests a low-effort approach to reducing diver impacts by using a coral-safe diving reminder. Comparisons of benthic cover, genus diversity, and health impacts did not reveal any significant differences between pairs of *often dived* and *rarely dived* sites, although it is likely that the damage and mortality caused by recent bleaching events may be masking the smaller impacts of scuba divers. A single-sentence coral-safe diving reminder delivered as part of the standard pre-dive briefing was highly effective in reducing both accidental and intentional contacts with reef. Divers who received a coral-safe diving reminder made 72% fewer contacts with the reef, and about 60% fewer contacts with live corals specifically, than divers who did not receive a reminder. Predictors of high-impact divers were identified, including camera users, gloves users, visiting divers, large groups, and poor buoyancy control. The results of this study may be used by diving professionals to identify potential high-impact divers who may benefit from increased supervision. Based on the results of this study, recommendations for reducing the impacts of scuba divers on coral reefs are presented for dive operators, regulating bodies, and individual divers.

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1. Introduction

1.1 Coral reefs in decline

Coral reefs around the globe are increasingly threatened by a wide variety of stressors, including overfishing, destructive fishing, pollution, coastal development, sedimentation, disease, tourism/recreational use, and climate change. While all coral reefs are affected by some combination of these stressors, climate change is perhaps the only universal stressor, affecting all reefs regardless of location or human population. Coral reefs have evolved to recover from regular natural disturbances, but global climate change is driving increasingly frequent bleaching events on reefs around the globe. Corals are limited to a relatively small thermal niche, and rising sea surface temperatures threaten corals in their current range, most severely in biodiversity hotspots (Descombes et al. 2015). Severe coral bleaching has led to massive die-offs, particularly for fast-growing branching and table corals, which are structurally important for reef-associated organisms. The 2016 bleaching event on the Great Barrier Reef, perhaps the most well-publicized major bleaching event in recent years, resulted in over 50% mortality at many sites; bleaching in 2017 caused more damage, and as bleaching events become more frequent, coral reefs may be unable to recover and are expected to continue to degrade (Hughes et al. 2018). Rising water temperatures and increasing ocean acidification have also been shown to slow coral growth, decrease biodiversity, and alter the microbiomes of corals and other reef-associated organisms (Fabricius et al. 2011; Webster et al. 2016; Sunday et al. 2017).

Local stressors compound the problem of climate change, as they reduce coral fitness and resilience to bleaching, thereby inhibiting reef recovery after bleaching events (Carilli et al. 2009). Coral reefs are a critical resource to human communities, who may rely on their reefs for sustenance, livelihoods, recreation, and traditional or cultural practices. For coral reef managers looking to protect their imperiled resources, reducing local stressors may be the only viable local-level course of action to improve conditions for their coral reefs.

1.2 Reducing local stressors through stakeholder participation

Reducing local stressors is no small task, as it requires buy-in from stakeholders. Stakeholders may be unsupportive of not only the actions needed to reduce local stressors to coral reefs, but of the coral reef managers themselves, especially when management actions are considered unfavorable by the local community or create conflicts between user groups (de Andrade & de Oliveira Soares 2017). Marine protected areas (MPAs), for example, can be contentious with fishing communities who worry about their livelihoods and food security. When MPA planners take into account the socioeconomic situation of local fishers by ensuring "access to alternative livelihoods, information about conservation rules, and a relationship with conservation authorities," MPAs are more likely to improve the economic situations of affected communities, effectively protect coral reef resources, and achieve higher compliance with rules (Eriksson et al. 2019). Successful MPAs can improve reefs and fisheries, reduce poverty through tourism jobs, create better living conditions, and empower local people; unsuccessful MPAs can fail to protect reefs, restrict livelihoods, threaten food supplies, prohibit traditional practices, encourage unequal distribution of wealth, worsen living conditions, and even incite violence (Christie 2004). Poor communication, outreach, and transparency from managers can result in a lack of trust from the community; conversely, attracting participation from community members can be difficult for managers, and many managers do not know how to effectively make use of public participation (Bennett & Dearden 2014). Pushback from local businesses and politicians can make it difficult to pass environmental legislation or fight building projects that could impact coral reefs. Even restrictions on recreational activities that have demonstrated negative environmental impacts, such as scuba spearfishing, are often viciously opposed by local stakeholders. Harmful activities that have already been made illegal, such as dynamite or cyanide fishing, can be difficult to monitor or enforce, especially in remote areas.

Successful reduction of local stressors can only be achieved with stakeholder buy-in, but with limited time and resources, managers must choose carefully which stakeholders to appeal to and which stressors to address. Decades of psychological research into health and environmental behavior shows that campaigns to educate the public rarely result in significant behavioral changes, but the use of incentives and prompts can increase the efficacy of an informational campaign (Kennedy 2010; Kelly & Barker 2016). Monetary incentives, such as a cash reward or savings, are certainly effective in changing behavior, especially when used in tandem with moral incentives to “do the right thing.” However, incentives do not need to include monetary or material prizes; pride, public recognition, fun, making friends, and the feeling of contributing to something can also be very attractive incentives. For example, the RARE Center for Tropical Conservation program called “Promoting Protection Through Pride” resulted in successful local-scale conservation awareness campaigns in Latin America, the Caribbean, and the Pacific (Butler 2000).

Citizen science programs are an example of successful stakeholder buy-in and public participation without the use of material incentives. Citizen scientists have made significant contributions to marine management and restoration activities (Hesley et al. 2017). Citizen scientists have assisted with population tracking of whales (Higby et al. 2012), turtles (Bell et al. 2008), sharks (Davies et al. 2012; Hussey et al. 2013; Vianna et al. 2014), and manta rays (Jaine et al. 2012; Germanov & Marshall 2014); identifying and documenting rare species (Chin 2014); and reef monitoring programs such as Reef Check (Forrester et al. 2015; Done et al. 2017), Eye on the Reef (Beeden et al. 2014), and CoralWatch (Marshall et al. 2012). Scientists are often distrustful of citizen science, citing a dearth of citizen science projects that meet their needs, inconsistent data quality across citizen science projects, and the acknowledgement that not all science is well-suited for citizen science projects (Burgess et al. 2017). However, the challenges to citizen science have been well documented; with careful project planning, adequate training of volunteers, and calibration and validation of data, many citizen science projects have the potential to make large impacts (Conrad & Hilchey 2011). Scuba divers report high interest in citizen science activities, with more than 50% expressing interest in participating in marine citizen science projects (Lucrezi et al. 2018). While citizen science programs may not reduce local stressors directly, they can encourage stakeholder participation and interest in coral reef conservation, and they provide data that may otherwise not have been obtained.

Stakeholders can also be recruited for non-scientific reef resilience actions, such as public beach cleanups to remove trash from beaches and reef; tree plantings to reduce soil erosion and resultant sedimentation onto reefs; and the control of invasive species, such as crown-of-thorns starfish and lionfish. The Great Barrier Reef Marine Park Authority allows some divers to assist with the control of crown-of-thorns starfish (*Acanthaster plancii*) populations, even providing a handy guide complete with injection methods, safety considerations, and a section on crown-of-thorns starfish biology and ecology (Great Barrier Reef Marine Park Authority 2017). In the Caribbean, where invasive lionfish (*Pterois volitans/miles*) have decimated local fish populations, competitive lionfish hunting derbies have become popular (Malpica-Cruz et al. 2016). The Caribbean island of Bonaire has banned spearfishing, but the Bonaire National Marine Park administers a lionfish control program that provides workshops, permits, and bespoke lionfish-hunting gear to divers, resulting in a significant drop in local lionfish populations and a new market for lionfish as a food source (de León et al. 2013; Carballo-Cárdenas & Tobi 2016).

Tourism and recreational impacts are often overlooked as local stressors, especially in communities that are economically dependent on tourism. Eco-tourism is a fast-growing industry, and many tourists travel specifically to see natural wonders. Coral reef tourism accounts for a significant share of the economy in many coastal communities, and scuba diving tourism can be a sustainable industry if properly managed. Scuba diving is an expensive activity, and scuba divers tend to be wealthier and more highly educated than the population at large (Garrod & Gössling 2008; Sports & Fitness Industry Association 2015). Willingness-to-pay studies have found that scuba divers are generally amenable to paying fees to dive, especially in marine preserves and national parks (Peters & Hawkins 2009). Several MPAs are fully-funded by user fees, but most MPAs do not currently charge fees despite user willingness to pay, representing a significant and underemployed source of funding for coral reef protection (Terk & Knowlton 2010; Thur 2010). Divers are willing to pay more for healthier and more diverse reefs (Polak & Shashar 2013; Gill et al. 2015), larger fish (Shideler & Pierce 2016), and uncrowded dive sites (Zhang & Chung 2015). Specific types of diving, such as shark diving and "macro" diving, confer economic value to these organisms that may be leveraged for their protection (Vianna et al. 2011; Dicken 2014).

Businesses, particularly tourism businesses, are an often-overlooked stakeholder category, but they are perhaps the most promising when it comes to garnering support and action for local coral reef management. In areas with marine eco-tourism, businesses such as hotels, scuba diving companies, fishing charters, and eco-tour guides share a common interest in protecting coral reef resources, since a degradation or loss of resources would negatively impact their business. Lucrezi and Saayman (2017) found that many dive tour operators are aware and interested in eco-friendly options for their businesses, such as recycling and using more fuel-efficient boat engines. However, most operators did not actually implement eco-friendly options, citing a lack of economic incentive and low customer interest in sustainability. For businesses who are interested in their ecological impact on coral reefs, there are only a handful of voluntary sustainable certification programs. The two major certification programs are the U.S. National Oceanic and Atmospheric Administration (NOAA) Blue Star program, which awards certifications to dive operators and fishing charters that operate sustainably within the Florida Keys National Marine Sanctuary; and the Green Fins program, which certifies sustainable dive and snorkel tourism operators in Southeast Asia and the Caribbean. While these programs are voluntary and may raise the cost of doing business, sustainable certifications can also attract more eco-savvy customers who are willing to pay more to support sustainable businesses. Research into sustainable tourism shows that tourists with pro-environmental or pro-sustainable views are generally willing to pay more for green hotels, experiences, and destinations (J. Pulido-Fernández & López-Sánchez 2016). Younger, better educated, and higher income tourists are willing to pay more for eco-tourism, both in private business and in the form of fees/taxes collected to fund management and protection (Dodds et al. 2010). Furthermore, the World Economic Forum's travel and tourism sustainability index reveals that, despite long-standing myths that sustainability negatively impacts tourism, countries (especially developing countries) who improve their index of travel and tourism sustainability experience no change in their main economic indicators of tourism (Pulido-Fernández et al. 2015). Travel and tourism is one of the world's largest industries, accounting for 10.4% of global GDP and growing. Ten percent of all jobs worldwide in 2018, and 20% of all jobs created within the last five years, were in the travel and tourism industry (World Travel & Tourism Council 2019). Sustainable tourism is becoming more important now than ever before.

Not all eco-tourism activities are ecologically sustainable, and some resources are being "loved to death," including coral reefs. In tourism-dependent communities, protecting ecological resources is not only a biological imperative, but rather an economic necessity. As scuba diving and diving tourism continue to grow in popularity, dive operators and coral reef managers need to work together to protect their coral reef resources from overuse.

1.3 Scuba diver impacts on coral reefs

In low numbers, scuba divers typically have negligible effects on coral reefs, and the revenue generated from marine park fees levied on those visitors can fund management and efforts to protect marine habitats (Hawkins et al. 1999). However, overuse is a serious problem plaguing many popular diving locations across the globe, and high-intensity diving activity is strongly correlated with decline in reef health (Roche et al. 2016). Individual dive sites are generally estimated to have a carrying capacity of 5000-7000 dives per year, meaning that a single dive site can sustain several thousand dives annually without being negatively impacted, but many areas receive much higher usage (Dixon et al. 1993; Schleyer & Tomalin 2000). One of the world's most heavily dived coral reefs, a 12-kilometer stretch of coast in Eilat, Israel, is exposed to upwards of 250,000 dives each year. By all accounts this level of usage is unsustainable, and some researchers expect the reefs at Eilat to collapse within a few decades unless major management changes are made (Zakai & Chadwick-Furman 2002; Davenport & Davenport 2006). The central reef complex in Sodwana Bay, South Africa is exposed to 80,000-120,000 dives each year and is regarded by some coral reef scientists as a "lost cause" due to the continuing intense diving pressure on the small reef area (Walters & Samways 2001; Celliers & Schleyer 2008; Hasler & Ott 2008). Some heavily-dived areas of the Red Sea have seen a 43% reduction in coral cover and significant increases in algae cover in recent decades (Jameson et al. 1999), while popular sites in the Caribbean island of Bonaire were found to have 20% lower coral cover than nearby less-dived sites (Hawkins, Roberts, Hof, et al. 1999; Lyons et al. 2015). It is not uncommon to find that 50% or more of colonies, especially branching species, exhibit signs of diverinflicted damage at high-use sites (Rouphael & Inglis 2002; Hasler & Ott 2008; Hannak 2011; Krieger & Chadwick 2013).

Damage caused by reef users, mainly snorkelers and divers, has been recognized as a growing problem since at least the 1980s, and the problem continues to grow as diving tourism expands (Kay & Liddle 1989; Talge 1992; Rogers et al. 1998). Corals have the capacity to repair themselves when damaged, but many corals are being damaged more quickly than they can repair themselves. Unsustainable levels of coral damage caused by divers and snorkelers have been widely reported from around the globe, including reefs in the Atlantic, Indian, and Pacific oceans (Allison 1996; Rogers et al. 1998; Hawkins, Roberts, Hof, et al. 1999; Krieger & Chadwick 2013; Au et al. 2014; Gill et al. 2015; Renfro & Chadwick 2017). Divers can directly cause abrasions and breakages by kicking, grabbing, bumping, laying, or kneeling on coral, or by entangling their gear. Divers can also cause less direct damage by stirring up sediments, wearing chemical sunscreens, and feeding fish. Studies on diver behavior have found that most divers make contact with the reef at least once during a dive, and while most divers make few contacts and cause little to no damage, a few divers with poor buoyancy control can make hundreds of contacts and break dozens of corals in a single dive; for example, Harriott et al. (1997) found that 70% of observed damage was caused by just 4% of divers. While few of these contacts result in immediate and direct damage to corals, these small but chronic injuries can result in “death by a thousand cuts” for the affected corals (Camp & Fraser 2012; Chung et al. 2013; Krieger & Chadwick 2013). Snorkelers cause damage by kicking or standing on corals, causing breakages and abrasions, but this damage is restricted to shallow corals (Allison 1996; Plathong et al. 2000; Hannak 2011). Snorkeling areas tend to be poorly managed, further worsening ecological impacts on corals and other benthic organisms (Gill et al. 2015; Renfro & Chadwick 2017). Divers are not as restricted by depth and can venture into deeper waters, which may have high coral cover and more fragile species, such as plating or branching corals (Meyer & Holland 2008).

Breakages in small amounts are not necessarily detrimental to coral health; fragmentation of branching corals occurs naturally and is an asexual reproduction mechanism for some species. Abrasions, which can be caused naturally by sand, algae, and other biotic interactions, remove the coral's mucus layer and carry a risk of algal colonization. Capacity to recover from an injury varies by species, as well as by the shape, size, type, and position of the injury. Usually corals can recover from naturally-occurring occasional breaks and abrasions with few or no lasting negative effects. Corals must race to regenerate lost tissue before other organisms, namely algae or pathogens, can settle on the injury and cause greater tissue loss to the coral (Hall 2001). Chronic injuries result in slower growth and reproduction, since the coral’s energy is focused on recovery (Hawkins & Roberts 1993). Repeated and sustained damages caused by scuba divers can lead to faster rates of injury than recovery, which in turn leads to reduced defense against algae, corallivores, and disease. Fragmentation may also reduce fecundity because polyps in small colonies typically produce significantly fewer eggs than polyps in larger colonies (Sakai 1998; Beiring & Lasker 2000). Additionally, many corals have a minimum size below which they fail to reproduce at all, and fragmentation may reduce a colony to a pre-reproductive state (Kai & Sakai 2008)

Sediment impacts may be significantly higher at intensively-dived sites than in less-dived areas, especially near the entrances of dive sites (Hasler & Ott 2008). Sediments kicked up by divers settle on coral polyps, which can inhibit feeding and reduce the amount of light that reaches coral’s photosynthetic zooxanthellae symbionts. Corals are capable of removing sediment, but this drains the coral of energy that could be used for growth, injury recovery, and reproduction (Hall 2001). Sediments have been shown to directly interfere with reproduction, with effects ranging from reduced larval settlement, lowered fertilization rates, increased mortality of recruits (Jones et al. 2015). High sedimentation has also been associated with an increase in sedimentation-associated tissue necrosis (Lamb et al. 2014).

Increases in diving pressure and coral damage lead to increased susceptibility to coral diseases. Coral diseases are becoming increasingly pandemic, and while many are either confirmed or suspected to be caused by infectious pathogens that spread through seawater, most coral diseases are poorly studied, especially outside of the Caribbean (Myers & Raymundo 2009). Reefs frequented by divers and snorkelers may have disease rates 3 to 18 times higher than nearby less-frequented reefs (Lamb & Willis 2011; Lamb et al. 2014). Coral diseases can cause bleaching, tissue loss, reduced reproduction, slowed growth, total colony mortality, and even changes in community structure and diversity (Goreau et al. 1998; Raymundo et al. 2008). Increased coral disease has been linked to elevated nutrient concentrations from sewage outfalls and terrestrial runoff resulting from coastal developments; these problems will continue to plague reefs as tourism rates grow (Lamb & Willis 2011; Redding et al. 2013). Injuries, such as breakages and abrasions, may provide entry points for pathogens to infect a coral colony (Page & Willis 2008). Additionally, sunscreens used by snorkelers and divers promote viral infections, cause abnormalities in coral larvae, and contribute to coral bleaching, even in extremely low concentrations (Danovaro et al. 2008; Downs et al. 2015). Sunscreen agents may also undergo photodegradation, resulting in by-products that are toxic to corals (Giokas et al. 2007). As coral cover declines around the globe, coral isolation and outbreaks of disease may lead to future declines in coral genetic diversity and greater susceptibility to climate change, bacterial and viral infections, and a host of other serious threats to corals (Altizer et al. 2003).

The domino effects of diver damage do not end with disease; coral predation rates are also higher at heavily-dived sites, likely due to the heightened physiological stress caused by increased injury, disease, and sedimentation. Divers may also be affecting the population of predators of corallivores, leading to decreased population control of corallivores. Guzner et al. (2010) report increased predation by the corallivorous snail *Drupella cornus* on a heavily dived site, causing significant tissue mortality in hard corals; no such effect was found on nearby sites closed to divers. Crown-of-thorns starfish (*Acanthaster planci*) have also been shown to feed preferentially on stressed corals, even when healthy corals are available, leading to further damage and decline, particularly in sensitive corals like *Acropora* (Booth 2011; Bright et al. 2015).

In addition to reduced coral cover and coral health, high use by scuba divers can also lead to reductions in structural complexity (Hawkins, Roberts, Van't Hof, et al. 1999; Lyons et al. 2015), changes in benthic assemblages (Bravo et al. 2015; Garrabou et al. 1998; Hasler & Ott 2008; Lyons et al. 2015), and changes in fish assemblage patterns (Albuquerque et al. 2015; Gil et al. 2015). Activities associated with diving and snorkeling, such as fish feeding and marine mammal harassment, can also result in ecological and behavioral disturbances (Davenport & Davenport 2006; Giglio et al. 2018; De Brauwer et al. 2019). The mere presence of scuba divers can also alter behavior, even if dive operators follow rules of conduct to minimize their effect (Barker et al. 2010). Clearly, careful monitoring and effective protections against human activities are crucial to maintaining the long-term health of coral reefs.

1.4 Scuba diving on Guam

Guam is a small island territory of the United States located in the Pacific Ocean (Figure 1, page 34). The island is 544 km^2 and has a population of roughly 160,000 people (US Census Bureau 2014). Guam's primary economic drive is the United States military, which accounts for about 33% of Guam's GDP (Central Intelligence Agency 2019). Guam is an important strategic holding in the Pacific, and the military owns about 30% of the island's land. Between Andersen Air Force Base and Naval Base Guam, roughly 7,000 troops are stationed on the island (Burrows 2017). However, this number is expected to increase by nearly 4,500 as the United States Marine Corps builds their own base and relocates soldiers from Okinawa, Japan and the United States mainland to Guam (South 2019). Tourism is the island's second-highest economic driver, accounting for 34% of non-military employment on Guam, supporting 21,000 jobs, and generating $1.75 billion for the island's economy in 2018 (Guam Visitors Bureau 2018a).

Guam's coral reefs support over 5,000 species, many of which are economically important as either food or tourism drivers, and more than 300 species of stony corals (Burdick et al. 2008). Like most reefs around the world, Guam's coral reefs have declined drastically in recent years. Coral surveys in the 1960s reported an average coral cover of about 50% around Guam (Randall 1973), but by 2005 island-wide coral cover had declined to 26% (Burdick et al. 2008). Elevated sea surface temperatures caused severe bleaching and mortality in 2013, 2014, 2016, and 2017, while ENSO-related extreme low tides caused air exposure and widespread mortality of shallow reef flat corals in 2015 (Raymundo et al. 2019). Five successive years of thermal stress, compounded by disease and crown-of-thorns starfish outbreaks, have taken their toll on the island's reefs. Between 2013-2017, live coral cover island-wide decreased by roughly a third, with corals on the island's east coast declining by 59% (Raymundo et al. 2019). Shallow reef-flat staghorn populations, a critical fish habitat, have decreased 53% island-wide, with some populations experiencing complete mortality (Raymundo et al. 2017).

Guam's reefs are also among the most overfished in the world, leading to suppressed herbivory and increased algal growth (MacNeil et al. 2015). Survey data indicate that 30% of Guam residents fish or gather marine resources (such as sea cucumbers and shellfish), and that 94% of fishers do so to feed themselves or their families (Gorstein et al. 2016). As of 2019, there are five marine protected areas (MPAs) established, but with only six conservation officers for the entire island and surrounding waters, enforcement is difficult and poaching is prevalent but poorly documented. There are no user fees for MPAs, and while a willingness-to-pay study in 2016 found that users were amenable to fees for improved reef conditions, there are currently no plans to introduce MPA fees (Grafeld et al. 2016). The most recent valuation study of Guam's reefs (van Beukering et al. 2007) estimated the total worth of Guam's reefs to be US$127 million; accounting for inflation, Guam's reefs are worth roughly US$157 million annually in 2019. A decline in reef health will not only lead to economic loss, but also to cultural loss. While subsistence fishing is no longer as critical to survival as it once was, the sea remains an important part of the native CHamoru people's culture (Allen & Bartram 2008). Many aspects of the CHamoru culture, including oral histories, traditional seafaring and fishing practices, and language, would be deeply impacted by the loss of coral reefs.

Coral reefs also play an important role in coastal protection, mitigating threats to critical land and freshwater resources. The physical roughness of reefs dampens wave action by transferring energy from waters into reef structures (Kench & Brander 2006). Coral reefs are particularly important during extreme storm events, as they can dissipate wave energy to reduce storm surge, mitigate debris movement, and capture sediment. Reducing storm surge is incredibly important for human populations, as it not only mitigates damage to coastline structures, but it also reduces the threats of shoreline erosion, inundation of low-lying areas, and salinization of groundwater (Spalding et al. 2014). On many Pacific islands, including Guam, the primary source of freshwater is groundwater, which generally occurs as a thin layer of freshwater overlying seawater in permeable aquifers (White & Falkland 2010). Current climate change models predict that sea levels will continue to rise, storms will increase in severity, and weather patterns (such as dry/wet seasonality) will change, all of which may negatively impact agriculture and groundwater sources. Rising sea levels and flooding of low-lying areas can irreversibly damage agricultural areas, making them too salty for crop production and threatening food supplies. Periods of drought, such as the extreme drought experienced in Palau in 2016, can reduce an aquifer's ability to regenerate water supply. Droughts can lead to groundwater salinization and can affect human health, agriculture, and the economy. Protecting land and groundwater sources from salinization is critical for Pacific islands, as desalinization is prohibitively expensive (White & Falkland 2010). Cesar et al. estimate that the global coastal protection value of coral reefs exceeds US$9 billion (2003). van Beukering et al. estimate the coastal protection value of Guam's coral reefs at $8.4 million per year, roughly 7% of the total estimated economic value of Guam's reefs (2007).

Roughly 65% of visitors come to Guam to experience the island's natural beauty, particularly the marine resources, so a decline in Guam's coral reefs will also negatively impact the island's tourism industry (Guam Visitors Bureau 2018a). Guam welcomed more than 1.5 million visitors annually from 2016-2019, and 1 in every 3 jobs on Guam is related to the tourism industry. Most visitors come from South Korea (45%) and Japan (41%) (Guam Visitors Bureau 2019). Visitors tend to be relatively young (about half are 25-39 years old), and many are repeat visitors (Guam Visitors Bureau 2018a). Nearly a third (28%) of Japanese visitors snorkel during their visit, 7% scuba dive, and another 6% visit the "Seawalker" attraction, which allows non-divers to wear a helmet and walk along the seafloor at a depth of roughly 5-8 meters (Guam Visitors Bureau 2018b). For decades, Japanese nationals made up the majority of Guam's visitors, but in the past few years South Koreas have become the largest share of the market. Many Korean visitors report snorkeling (47%) during their stay, and about 8-10% scuba dive (Guam Visitors Bureau 2018c). Roughly 17% of visitors from Taiwan, Russia, and Hong Kong list scuba diving as their top reason for visiting Guam (Guam Visitors Bureau 2017).

No agency or organization tracks diving activity nor the number of scuba divers on Guam. Airport exit surveys conducted by the Guam Visitors Bureau estimate that 10% of visitors, or roughly 150,000 people annually, scuba dive during their visit. There are no reliable current numbers for local divers, but the most recent valuation of Guam's coral reefs estimated that 19% of residents, or 30,000 people, scuba dive an average of 2.65 days per year (van Beukering et al. 2007). Combining the estimated numbers of resident and visiting divers, roughly 180,000 divers are using Guam's reefs every year—more than the island's population. If each diver makes, at minimum, two dives (a single boat trip, or two shore dives) per year, Guam's reefs are supporting a bare minimum of 360,000 dives per year. van Beukering et al. (2007) estimate that Guam's waters contain 71.66 km^2 of coral reef, of which 21.8 km^2 is considered "high value tourism" reef within 500 m of a popular tourist site. The highest value reef category covers just 0.33 km^2 (or 0.4% of Guam's total reef area) but is valued at $1.78 million in economic value. Coral reefs are a critical part of the island's economy and their continued degradation could lead to serious economic losses, so maintaining the health and beauty of the coral reefs is essential for the island's tourism-based economy.

Guam's diving industry is currently unregulated by the local government, and the impacts of divers on the island's coral reefs are entirely unknown. Policymakers and stakeholders need information to make evidence-based decisions about the management of the reefs. This study aims to bridge the knowledge gap about the scuba diving industry and the impacts of divers on Guam's coral reefs.

1.5 Diver impact studies

To date, 20 studies have been published examining the impacts of scuba divers in various ways. A basic summary of these studies reveals a wide range of contact rates and a variety of significant or nearly significant factors (Table 1). Divers who used cameras and/or gloves consistently made significantly more contacts than divers without these accessories. Depth, dive site type, dive time (night or day), boat versus shore dive, formal education, certification level, and number of lifetime dives were all found to be significant factors in at least one study. Two studies found gender to be a significant factor, but with opposite results. Fins, gauges, and hands were the most common body parts/equipment that contacted the reef. Damage to corals was evaluated in a variety of ways and is difficult to compare between studies, but records of coral damage ranged from 3% to 37% of all contacts. Between 13% to 97% of all divers caused at least one instance of damage.

Table 1. Summary of published diver contact rate studies.

Study	Location	Sample Size	Contact Rates (60 minutes)	Significant Factors ($p < 0.05$)
Barker & Roberts 2004	St. Lucia	353	15 ± 2.4	Night diving Camera use
Camp & Fraser 2012	Florida Keys, USA	83	22.2 ± 1.3	Gloves (coral contacts only)
Chung et al 2013	Hong Kong	81	34.2	Camera use Education
Di Franco et al 2009	Italy	28	21.6	None
Giglio et al 2018	Arraial do Cabo Marine Extractive Reserve, Brazil	180	14.4 ± 3	Camera use
Giglio et al 2016	Arraial do Cabo Marine Extractive Reserve, Brazil	142	15.6 ± 15	Camera type Special equipment use Artifical reef
Hammerton 2016	New South Wales, Australia	183	27.6 ± 25.6	Certification level Age range No. of lifetime dives
Hammerton 2017	New South Wales, Australia	400	32 ± 48	No. of days since last dive Location of certification Awareness of MPA zoning Camera use Experience Depth
Harriott et al 1997	Eastern Australia	Not listed	62 ± 96 to 242 ± 171	Training Experience
Luna et al 2009	Spain	181	247.2 ± 21	Gender (Males > Females) Experience Camera use Lantern use
Medio et al 1996	Ras Mohammed National Park, Egypt	48	12	Camera use

Table 1. (continued)

Study	Location	Sample Size	Contact Rates (60 minutes)	Significant Factors ($p < 0.05$)
Poonian et al 2010	Rock Islands, Palau	124	5.2 ± 1.6 to 17.8 ± 3.5	Glove use Camera use
Roche et al 2016	Philippines	100	7.2 ± .6	Camera use Muck stick use Green fins compliance
Worachananant et al. 2008	Surin Marine National Park, Thailand	108	97.2 ± 11.4	Camera use Gender (Females > Males) Experience
Zakai & Chadwick-Furman 2002	Eilat, Israel	251	15 ± 15.6 to 33 ± 27.6	None
Rouphael & Inglis 1997	Agincourt Reefs, Great Barrier Reef, Australia	150	32.5 ± 3.8	None
Toyoshima & Nadaoka 2015	Okinawa, Japan	105	31.8	Buoyancy control
Webler & Jakubowski 2016	Puerto Rico, USA	325	3.12	Gender (Males > Females)
Liew et al 2001	Redang, Malaysia	112	5.8	Certification level

Seven of these studies investigated methods to reduce diver contacts with the reef (**Table 2**). Medio et al. (1997) observed divers at an Egyptian resort for 7 minutes both before and after he delivered a 45-minute illustrated environmental briefing which covered "various aspects of coral biology, impacts caused by divers, and the concept of a protected area." After the briefing, divers were treated to an in-water lesson to demonstrate the different types of living and non-living substrata. This educational briefing significantly reduced diver contacts but required a large investment of time, effort, and resources.

Barker and Roberts (2004) tested the effect of a one-sentence environmental briefing given by a dive guide in St. Lucia. Their minimal briefing had no effect on contact rates, but they found a significant reduction when divers' contact with the reef was brought to their attention by dive leaders. Worachananant et al. (2008) reminded Thai divers to "be careful not to touch or break living organisms, especially coral" during "a short pre-dive presentation." Divers who attended this briefing made significantly fewer reef contacts than divers who did not attend.

Table 2. Summary of published studies of attempts to reduce diver contact rates.
Stars denote significant ($p < 0.05$) differences between control (standard dive briefing) and treatment (environmental briefing) contact rates.

Study		Contact Rates (60 minutes)
Barker & Roberts 2004	Control	15 ± 2.4
	Treatment	(no difference)
Camp & Fraser 2012	Control	22.2 ± 1.3
	Treatment*	9.6 ± 4.8
Giglio et al 2018	Control	14.4 ± 3
	Treatment*	4.2 ± 0.6
Hammerton 2016	Control	27.6 ± 25.6
	Treatment*	2.8 ± 4
Medio et al 1996	Control	12
	Treatment*	3.4
Toyoshima & Nadaoka 2015	Control	6.7 (divers with buoyancy control)
	Treatment *	2.8
	Control	20.6 (divers without buoyancy control)
	Treatment	20.3
Worachananant et al. 2008	Control	45 ± 6
	Treatment*	28.8 ± 4.8

In the Florida Keys, Camp and Fraser (2012) tested whether contact rates differed between customers of three standard dive operators and one NOAA Blue Star-certified dive operator. The Blue Star program was established by NOAA in the Florida Keys National Marine Sanctuary to recognize tour operators who promote responsible and sustainable marine recreation. Dive briefings were recorded, transcribed, and given a rating based on the length, content, and sincerity of the briefing. Higher-rated briefings were significantly correlated with lower numbers of diver contacts with the reef. Additionally, customers from the standard dive operators were more than twice as likely to interact with the reef compared to the Blue Star operator's customers. Through a questionnaire, the authors also found no differences in contacts between divers who did and did not have prior conservation education. Just over half (54%) of divers in this study felt that scuba diving negatively impacted coral reefs, and nearly all (95%) reported concern about the state of the world's coral reefs.

Toyoshima and Nadaoka (2015) investigated the effect of an environmental dive briefing on contact rates in Okinawa, Japan and found no significant differences before and after the briefing until the divers were separated by buoyancy control ability. While the majority of divers (84%) self-reported that they could maintain neutral buoyancy underwater, only 38% could actually do so. Thirty percent of divers with Rescue Diver certifications or higher could not maintain neutral buoyancy, and 90% of open water divers could not maintain their buoyancy. The environmental briefing significantly reduced the contact rates of divers who *could* maintain neutral buoyancy but had no effect on the divers who could not.

Hammerton (2017) tested whether a low-impact diver (LID) training affected divers' contact rates. Students in the course were given classroom and pool training, and they were observed during a pre-training and post-training dive. LID training significantly reduced diver contacts, but as the author acknowledges, this study may have been confounded by the fact that the students were aware of being watched. Additionally, all divers in this course were active and willing participants in a course to improve their diving skills. This study supports the idea that divers who are interested in improving their diving skills can achieve this goal if they are willing to pay for a specialized course. There is currently no publicly available data about divers' general interest in improving their skills but considering that several similar courses are already available from major diving agencies (e.g. PADI's peak performance buoyancy course), it can be assumed there is some level of interest.

Most recently, Giglio et al. (2018) tested whether an educational video briefing could reduce diver impacts. Preliminary observations of dive briefings revealed that low-impact diving was rarely mentioned and generally consisted of a single-sentence phrase such as "do not touch anything." Interviews with the dive guides revealed a lack of training, time, and interest as barriers to including environmental information in the dive briefings. With the cooperation of the dive operator, the researchers developed a multi-language 5-minute video briefing with information about coral-safe diving etiquette and low-impact diving techniques. The video briefing was highly effective in reducing both overall contacts and instances of damage to corals. Furthermore, divers generally rated the video briefings positively (mean = 9.3/10) and retained information from the video. The use of a video dive briefing could be advantageous to dive companies because it is relatively inexpensive to produce and requires no staff training—a potential boon for dive operators, which generally experience high staff turnover.

These studies provide a wealth of information about reducing diver impacts on coral reefs, but their methods are not universally applicable. As tourism on Guam continues to grow, reducing diver impacts on Guam's reefs is necessary for the continued health of the corals. However, many divers on Guam are local residents who dive frequently and may ignore repetitive dive briefings. Additionally, many of Guam's visitors have limited English language skill and may not be able to understand the dive briefing given by their boat captain or dive guide, regardless of how educational it may be. Guam's unique diver population requires a tailored, evidence-based approach to effectively reduce diver impacts and mitigate this stressor of our coral reefs.

1.6 Hypotheses

The purpose of this study is threefold: first, to investigate whether a coral-safe dive briefing can reduce diver impacts on coral reefs; second, to determine whether divers are causing significant impacts to Guam's coral reefs; and third, to identify if predictors of damaging diver behavior exist.

$H1_0$: A coral-safe diving reminder will have no effect on diver contact rates with coral reefs.

$H1_a$: A coral-safe diving reminder will have a significant effect on diver contact rates with coral reefs.

$H2_0$: Coral health and benthic cover will not differ between often-dived and rarely-dived sites.

$H2_a$: Coral health and/or benthic cover will differ significantly between often-dived and rarely-dived sites.

$H3_0$: No significant predictors of high-impact divers exist.

$H3_a$: Significant predictors of high-impact divers exist.

2. Methods

2.1 Overview

This study was comprised of three parts: testing coral-safe diving reminder, comparing coral health between *often dived* and *rarely dived* sites, and testing for predictors of high-impact divers. The coral-safe diving reminder was given by dive operator staff during the regular pre-dive briefings, and divers were clandestinely observed by the author to determine contact rates. Coral health surveys were conducted at three pairs of sites, with each pair consisting of one *often-dived* site and one *rarely-dived* site, to determine whether diver usage was impacting reef health. Finally, a combination of in-water observations and questionnaire data was used to test whether predictors of high-impact divers exist.

2.2 Coral-safe diving reminder

The effectiveness of the coral-safe diving reminder ($H1_0$) was tested with the cooperation of local boat captains. All dives were conducted at popular dive sites from commercial dive boats with Guam's largest company, Micronesian Divers Association (MDA). The dive shop owner and both boat captains were aware of the study, as their cooperation was necessary to conduct the study, but they were asked to treat the researchers as regular clients aboard the dive boats. Dive guides, instructors, and clients were unaware of the research being conducted, and divers who asked about researcher activities were told that researchers were observing fish behavior around divers. This deception was necessary, as divers would likely have changed their diving behavior if they were aware of being watched. The study was conducted from March 2016 to October 2017. Institutional Review Board approval was granted by the University of Guam Committee on Human Research Subjects (Appendix 9).

2.2.1 Coral-safe reminder delivery

This study was divided into a control phase and an experimental phase. During the control phase, MDA boat captains were unaware of the research and did not include any information about coral in their dive briefings. After the control data collection phase was completed, MDA boat captains were briefed on the research and asked to assist in the experimental phase by including in their dive briefing a short reminder about coral-safe diving. No detailed scripts were provided; instead, captains were asked to simply remind divers to avoid touching, kicking, or laying on corals. Captains rarely added any additional information to their coral-safe reminder, and the reminder itself usually took only seconds to deliver, although several times they forgot to mention it during their briefing. Captains were generally very cooperative with the coral-safe reminder.

2.2.2 Diver observations

In the water, divers were observed from a distance of three to five meters for five-minute periods during the dive. Exact time was kept with underwater stopwatches. All observation data were recorded by a single observer. Divers were not observed within the first five minutes of their dive to allow an acclimation period, nor were they observed during the last five minutes of their dive, as this period typically included the safety stop, during which divers were far above the reef in most cases. Details for each individual contact with the substrate was recorded, which included:

(1) reef substrate type contacted (e.g. live coral, macroalgae, sand)

(2) body part/gear used (e.g. hand, fin, gauge)

(3) visible damage to living organisms (i.e. breakage, abrasion, or sediment deposit)

(4) whether the contact was accidental or intentional

Divers were selected for observation based on convenience, with as many divers as possible observed on each dive. As the dive operator distributes numbered tags as a safety measure, these tags were used to uniquely identify divers underwater and on the boat. Occasionally divers from other dive boats were observed. Over the 20-month study period, a total of 461 individual divers were observed. Some divers were observed multiple times, yielding a total of 634 observations.

2.2.3 Site selection

Study sites were located on west-facing reefs off the island of Guam, the southernmost and largest (544 km^2) of the Mariana Islands. Guam is surrounded by fringing reefs, but nearly all commercial dive sites are located on the west-facing side of the island due to easier access and better water conditions; a few sites exist to the north and south, while east-facing sites are done only as shore dives.

Dive sites (Figure 1) varied greatly by location and were classified as one of four "site types" based on general characteristics such as dominant substrate and location. "Coral dominant" sites consist of fringing reefs in Tumon Bay, Agat, some sites inside Apra Harbor, and the ocean-facing side of the Apra Harbor breakwater; this site type combines more diverse coral communities with *Porites rus*-dominant sites. "Breakwater interior" sites were dominated by *Porites rus* colonies in shallow water, but had few coral colonies (primarily *Porites rus* and *Astreopora* colonies) and a greater cover and variety of sponges at depths beyond 12-15 m. "Pavement-dominant" dive sites sit along Orote point and are characterized by pavement (limestone that is highly weathered, flat, and mostly bare) and extremely low coral cover. "Wreck" sites include shipwrecks and World War II military dumping sites. Some sites, particularly wreck and breakwater sites, are too close together to be distinguished on the map; multiple dive sites may be represented by a single point.

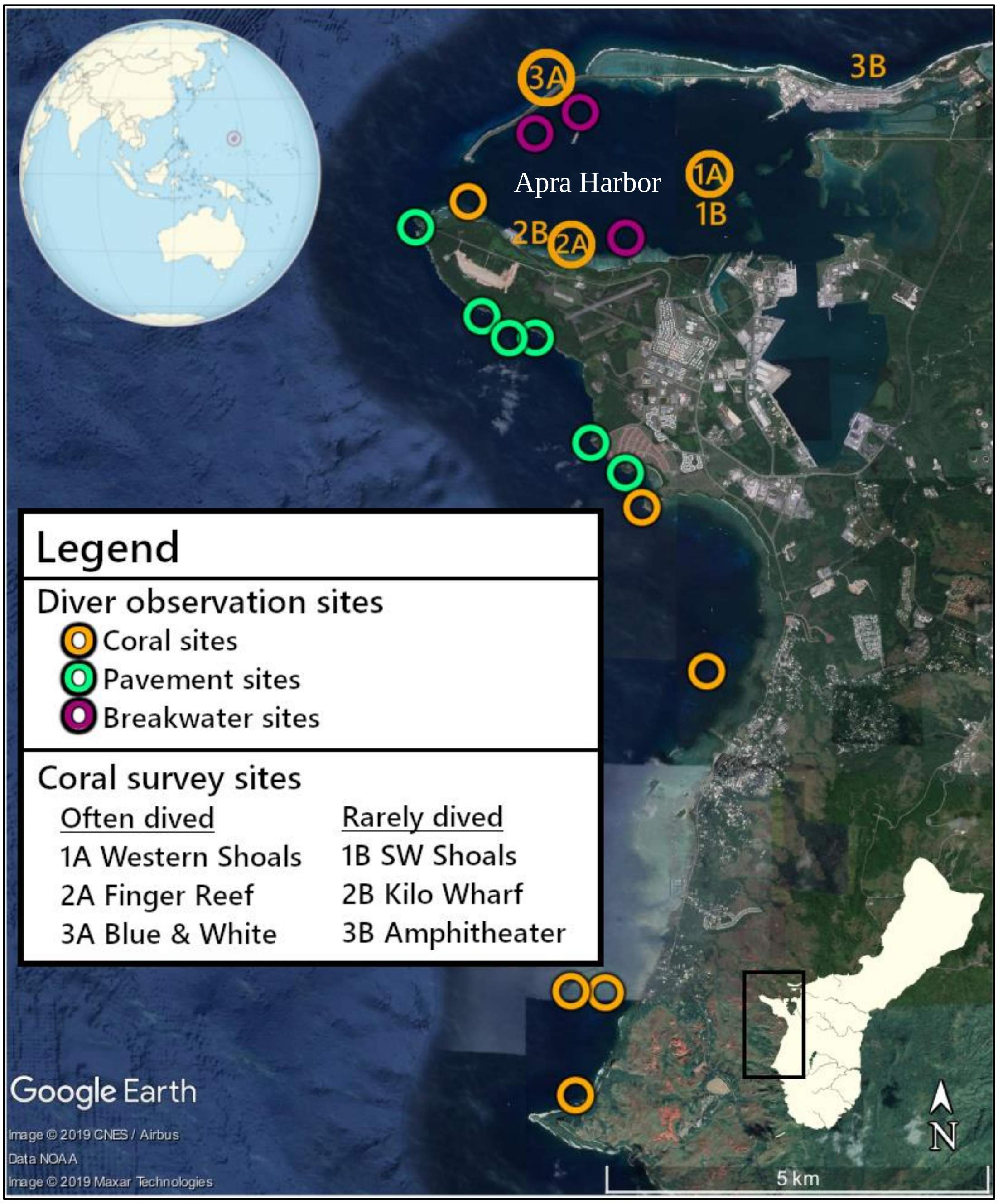

Figure 1. Map of the island of Guam and study sites. Coral survey sites that are circled were also diver observation sites. Shipwrecks were present at some Breakwater sites, but not at other types of diver observation sites.

2.2.4 Analysis

To test the hypothesis ($H1_0$) that diver contact rates do not differ by treatment with a coral-safe diving reminder, diver-substrate contact data were analyzed using Mann-Whitney U tests in R. Divers who were observed multiple times under the same experimental conditions, whether on the same day or across multiple days, had their contacts averaged across all dives; divers who were observed multiple times but under different experimental conditions were counted as separate individuals. Comparisons between the control and experimental groups were tested in four main categories:

(1) accidental contacts with *all substrates*

(2) intentional contacts with *all substrates*

(3) accidental contacts with *coral only*

(4) intentional contacts with *coral only*.

Diver contacts by body part were summarized but no statistical analysis was conducted on this data.

2.3 Coral health surveys

Coral health surveys were conducted to test the hypothesis ($H2_0$) that *often dived* sites and *rarely dived* sites did not differ significantly in several metrics of reef health.

2.3.1 Site selection

Coral health surveys were conducted at three pairs of dive sites (see Figure 1). Three of the sites were *often dived* sites, and for each site, a similar *rarely dived* paired site was chosen for comparison. The *often dived* sites were chosen for their popularity and high coral cover; due to their popularity, diver observations were also conducted at these sites. The *rarely dived* paired sites were chosen due to their proximity and similar species composition and coral cover to their *often dived* counterparts. Divers were never observed at the *rarely dived* sites during this study. The *rarely dived* sites were less popular due to access difficulties caused primarily by a lack of mooring buoys (Southwestern Shoals), generally rough conditions (Amphitheater), or military activity (Kilo Wharf). Sites were chosen based on author experience and local knowledge. Two pairs of sites were inside Apra Harbor and were dominated by *Porites rus* colonies. One pair of sites was located outside the harbor along the breakwater, and these sites had more diverse coral communities. Site pairs were chosen based on input from local coral reef researchers.

2.3.2 Survey methods

At each site, six 20 m transects were laid along the route of an average diver on a 60 minute dive. Along each transect, one diver conducted line-intercept surveys to determine benthic cover. Benthic cover categories consisted of live hard coral, soft coral, dead coral, recently-killed coral, macroalgae, crustose coralline algae, cyanobacteria, sponge overgrowth, silt/sediment, pavement, and rubble. A second diver conducted coral count and health surveys within a one-meter belt along the transect. Each individual colony within the belt was identified to the species or genus level and evaluated for size and health impacts (such as physical damage, bleaching, disease, predation, sponge or algal overgrowth, etc.). Coral size data were binned into six classes (Table 3). Octocorals, including blue coral (*Heliopora coerulia*) and soft corals (*Sinularia.*) were included.   Three transects were performed at a "deep" depth (roughly 20 m) near the mooring buoy or drop point, and three at a "shallow" depth (roughly 10 m) nearing the return to the mooring buoy or pick-up point. These routes were determined during diver observations and did not vary greatly; divers tended to spend the first half of their dive deeper, around 15-20 m, and the second half of their dive shallower, around 10-15 m, regardless of whether the dive was a drift dive or a return-to-boat dive.

Table 3. Coral size class ranges.

Size Class	Coral Diameter Range
1	0 – 10 cm
2	11 – 30 cm
3	31 – 60 cm
4	61 – 100 cm
5	101 – 200 cm
6	200 cm or larger

2.3.3 Analysis

Line-intercept transect data were recorded as percentage of total transect length for each substrate type. These data were cube-transformed and analyzed with ANOVA in R. Distributions and ANOVA residuals were tested for normality with a Shapiro-Wilk test; not all distributions were normal, but all residuals were, thus meeting the assumptions of the ANOVA test. Substrate types analyzed were live hard coral, sponge, and combined algae (including fleshy macroalgae, crustose coralline algae, red filamentous algae, and cyanobacteria.)

Coral health impact data were analyzed for pairs of sites rather than overall because each pair of sites was affected by unique conditions and stressors. Impacts were calculated as percentage of total colonies affected for each transect. Using transects as samples, comparisons between sites within pairs were made using a Mann-Whitney U test with Bonferroni-Hochberg corrections for multiple tests.

2.3 Predictors for high-impact divers

To test whether significant predictors for high-impact divers exist ($H3_0$), diver contact data were compared against other observational data and questionnaire data.

2.3.1 Observational data

During diver observations described in section 2.2.2, additional observational data was collected for predictor testing. Glove use, camera use, and observed buoyancy control level were recorded. Camera types were divided into three categories: GoPro-style, point-and-shoot, and DSLR cameras. Buoyancy control level was rated qualitatively based on criteria in Table 4. Group size was noted for each diver, and each group of divers was assigned a group identification number. For groups with a paid guide, guide/client status was recorded. Site type was included in this category.

Table 4. Buoyancy control assessments based on diver behaviors.

	Buoyancy Control Rating		
Observed Behavior	Poor	Fair	Good
Adds/dumps air from BCD	Frequently	Occasionally	Rarely
Difficulty maintaining depth during safety stop	Frequently	Occasionally	Rarely
Makes uncontrolled ascents/descents	Occasionally	Rarely	Never
Body position in the water column	Vertical	Semi-horizontal	Horizontal

2.3.2 Questionnaires

All divers were asked to complete short questionnaires (Appendix 1), and they were offered a small waterproof fish identification card as a reward if they completed the questionnaire. The questionnaire was available in English and Japanese, and it was administered during the surface interval between the first and second dive of the boat trip. The questionnaire included several standard demographic questions (age, nationality, education, etc.) as well as several questions about diving experience, certification level, recent diving activity, and self-reported diving skill. Divers were asked to rate their agreement or disagreement on several statements about coral reefs. These questions were designed to assess the diver's knowledge about coral reefs and collect self-reported information about their dive training using a five-point Likert scale design where 1 means "I do not agree not at all" and 5 means "I completely agree," with an option for "I don't know." These statements encompassed factual knowledge (e.g. "White corals are healthy corals"), opinions (e.g. "I know a lot about coral reefs"), self-assessed ability (e.g. "I am a skilled diver"), and training (e.g. "In my dive training, I was taught to avoid touching/kicking things"). Divers were also asked to report how often they do a variety of actions while diving using a five-point Likert scale ranging from "Never" to "Every dive", with an option for "I don't know." These questions fell into four main categories: safety (e.g. "How often do you perform a safety stop at the end of a dive?"), gear usage ("e.g. "How often do you use a camera while diving?"), skill level (e.g. "How often do you accidentally bump or kick things during a dive?"), and intentional actions (e.g. "How often do you touch, grab, or poke corals during a dive?"). A "dummy" question was included to ensure that divers were reading the questions and answering appropriately; divers who failed the dummy question were not included in questionnaire-based analyses.

Questionnaires were offered to 528 divers on MDA boat trips, and a 78% participation rate was achieved. A total of 432 viable questionnaires collected, yielding a confidence interval of 4.71 (assuming a population of 180,000 and a confidence level of 95%). Divers who did not speak English or Japanese were given the option to complete the questionnaire but generally did not, or (in a few cases) completed it with the help of their dive guide. Observed divers from other boats were not offered questionnaires. Not all divers who were observed completed questionnaires; questionnaire data was available for 73.5% of all observed divers. For divers who refused questionnaires (typically due to seasickness or a language barrier) demographic data was sometimes able to be collected through conversation. The questionnaire included a question asking the diver for their diver tag number, allowing in-water observations to be linked to questionnaire responses.

2.3.3 Analysis

A variety of analytical techniques were employed to investigate whether any predictors of high-impact divers exist. Divers who were observed multiple times under the same conditions (e.g. carried a camera on both dives) had their contacts averaged across all dives. Divers who were observed multiple times but under different conditions (e.g. carried a camera on the first dive but not on the second dive) were counted as two individual divers for that particular condition. Contact rates were compared to questionnaire data and observational data using Kruskal-Wallis tests (with pairwise comparisons) and Mann-Whitney U tests using R, with Bonferroni-Hochberg corrections to account for multiple tests. Using the *Hmisc* package in R, number of individual contacts were correlated to (1) group size and (2) for paying clients, the contacts of their paid guide.

Significant predictors of high-impact diver behavior were identified using both individual comparisons and stepwise regression analysis. Correlation analysis was conducted to identify strongly covariant predictors. Predictor variables were chosen for testing based on their ability to be determined easily and noninvasively by diving professionals; for example, gender was tested, but income level was not. Buoyancy control was not included because a dive guide could not be expected to know a diver's abilities before the dive. Diver contact data were cube-root transformed but did not achieve normal distribution. Predictor variables were a combination of categorical (e.g. gender), nominal (e.g. diver certification level), and continuous (e.g. group size) variables. Categorical and nominal variables were dummy coded to allow their inclusion in the regression model. Stepwise regression was chosen over multiple linear regression to avoid issues with covariant predictors. An initial model was trained using R package *caret* with a maximum of 15 predictors incorporated into the model using backward selection. Using the predictors identified in the initial model, stepwise regression was used to achieve the maximum coefficient of determination with the fewest predictor variables. The resulting models did not meet all ANOVA assumptions. However, due to the robust nature of ANOVA testing and the negligible risk for harm from type I errors that may occur, regression results are reported for the purposes of assisting diving professionals with identifying divers who may benefit from increased supervision. Coefficients were standardized for reporting.

2.4 Additional analyses

Demographic data, Likert-scale data, and observed predictor variable (e.g. gloves, cameras, etc.) were analyzed using Chi square tests. Questionnaire responses were compared to other questionnaire responses using Mann-Whitney-Wilcoxon tests (with pairwise comparisons) and Kruskal-Wallis tests, with Bonferroni-Hochberg corrections to account for multiple tests.

Contact rates were compared to self-assessment statements from the questionnaire to determine (1) whether divers were aware of their skill ability, and (2) if their beliefs, knowledge, or opinions were related to their contact rates. Self-assessments are not considered predictors for the purposes of this study because they are not easily discernable without a questionnaire.

3. Results

3.1 Coral-safe diving reminder

The coral-safe reminder was highly effective in reducing diver-reef contact rates. Divers who received a coral-safe reminder made significantly fewer reef contacts, both accidentally ($p < 0.00001$) and intentionally ($p < 0.0001$) than divers who received no warning (Figure 2). Both accidental and intentional contacts overall were reduced by 72%. For contacts specifically with coral, divers who received the reminder exhibited much lower average contact rates, but these differences were not statistically significant. Accidental coral contacts were reduced by 56%, and intentional coral contacts were reduced by 65%.

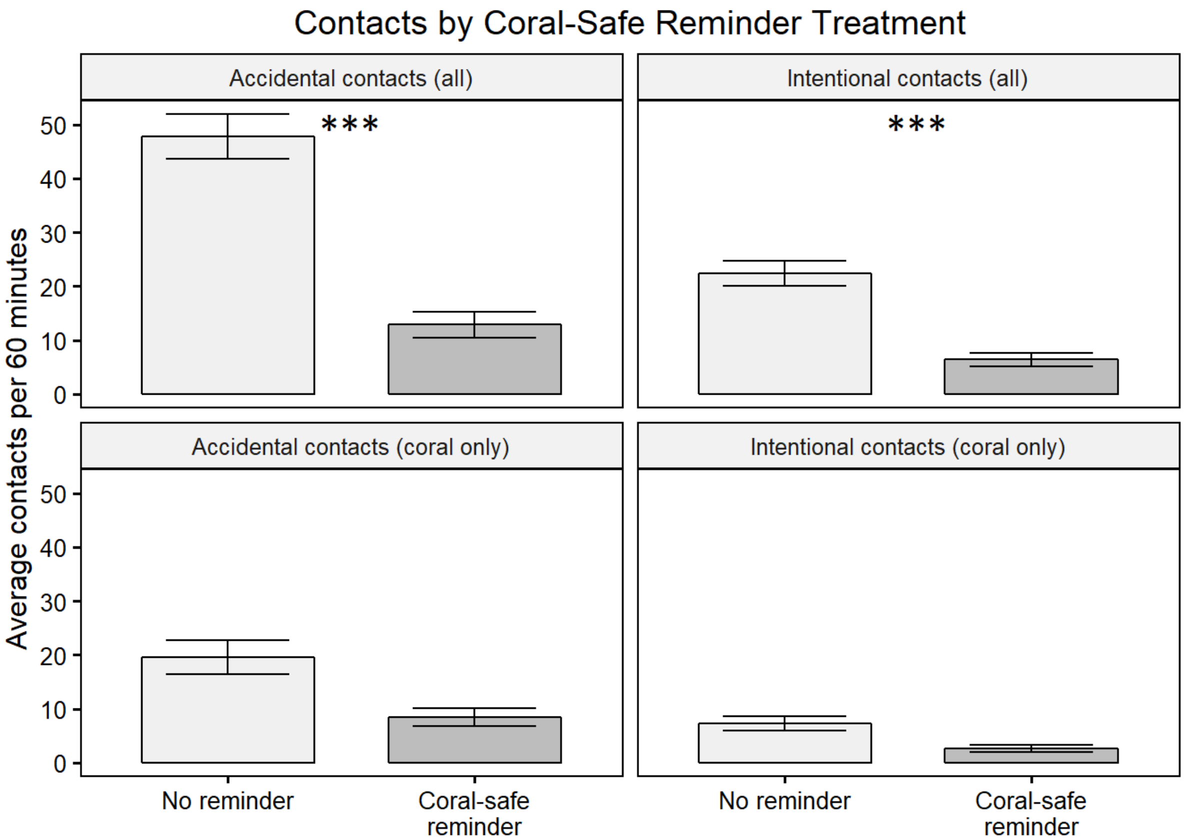

Figure 2. Average contact rates by coral-safe diving reminder treatment. (Stars denote significance: * = $p < 0.05$, ** = $p < 0.001$, and *** = $p < 0.0001$.)

3.1.1 Diver-reef contacts

A total of 2,890 diver-substrate contacts were observed throughout this study, of which 1,889 (65%) were accidental and 1,001 (35%) were intentional. Accidental contacts were almost entirely made by fins and dangling gear (such as gauges or safety sausages), while intentional contacts were primarily made with hands, fins, and knees (Figure 3). A coral-safe diving reminder did not result in any significant differences in diver contacts by body part.

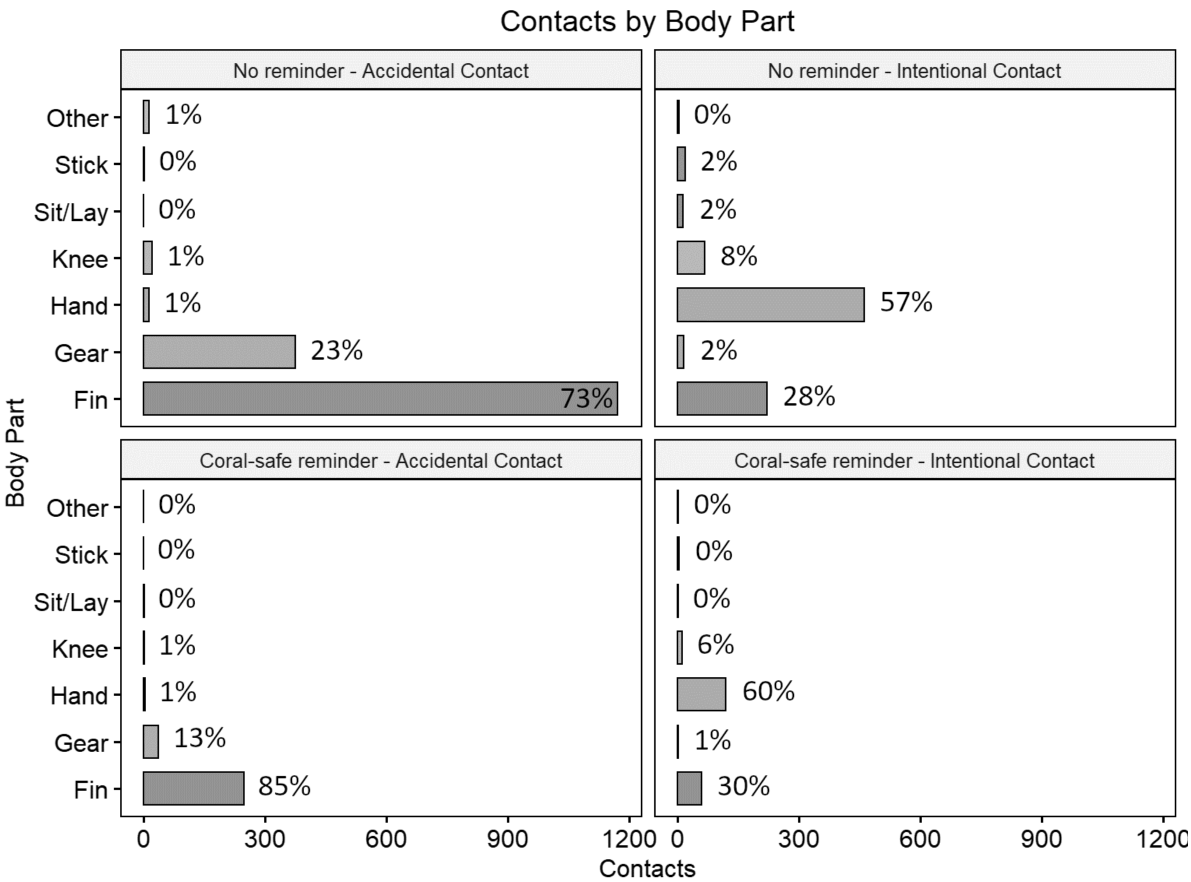

Figure 3. Observed diver contacts by body part. Most accidental contacts were made with fins, while most intentional contacts were made with hands.

Divers made more contact with live coral than any other substrate type (Figure 4). Divers were unlikely to accidentally touch animals, such as sea cucumbers, clams, sea stars, etc. Divers were occasionally observed intentionally picking up or poking creatures, but intentional contacts with animals were greatly reduced after receiving a coral-safe diving reminder. Contacts with live corals accounted for 45% of all accidental contacts and 38% of all intentional contacts (regardless of a coral-safe diving reminder), although these percentages were nearly twice as high at coral-dominant sites and much lower at site types with low coral cover, such as wrecks (Table 5). Divers who received a coral-safe diving reminder made fewer contacts with live coral, but a higher percentage of their contacts were with live coral.

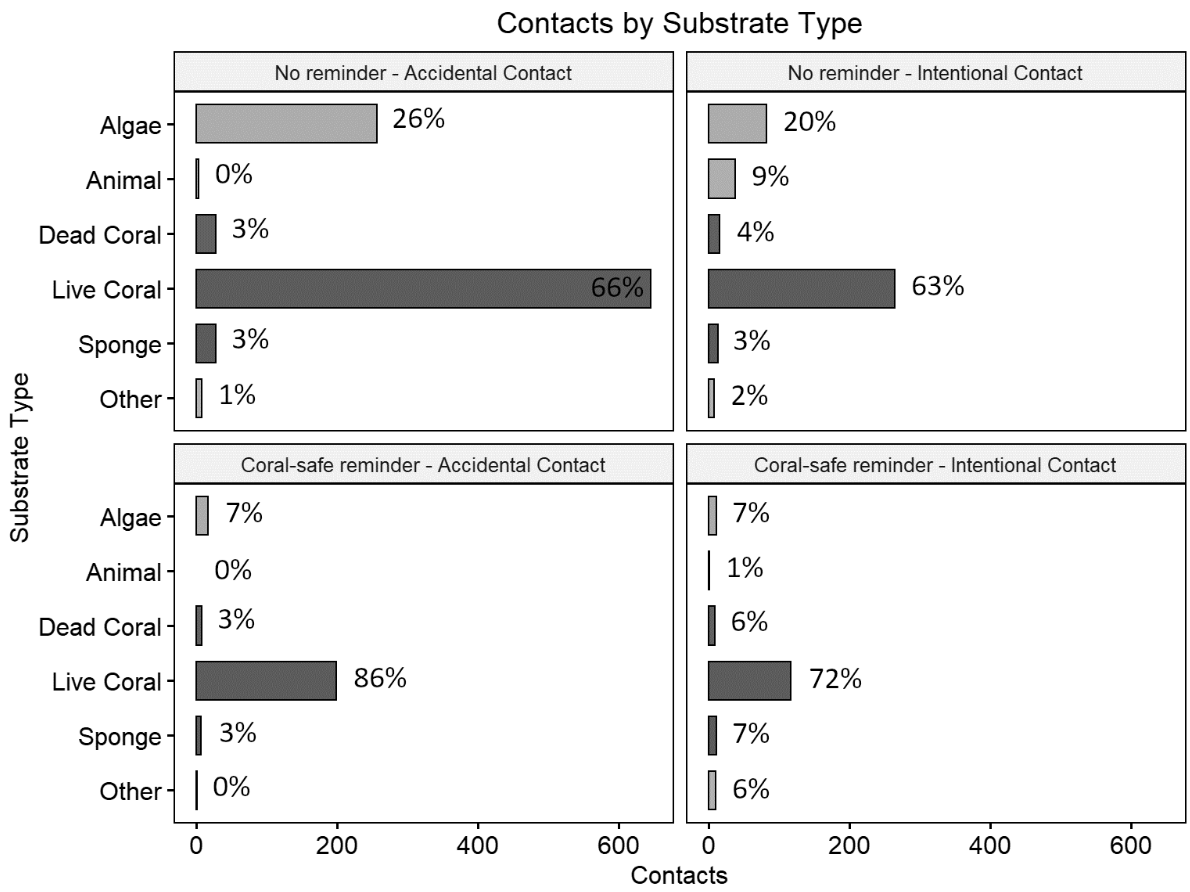

Figure 4. Observed diver contacts by substrate type. Divers mostly touched live corals.

Table 5. Proportions of accidental and intentional contacts with corals by site types.

Site Type	Estimated Coral Cover	Accidental Coral Contacts (% of total)	Intentional Coral Contacts (% of total)
Coral dominant	High	83.5%	74 .3%
Breakwater interior	Medium	42.6%	21.0%
Pavement dominant	Low	16.3%	12.7%
Wreck	Very low	1.7%	0.0%

The majority of contacts were made by relatively few divers. A total of 548 unique divers were observed throughout this study. Of these, 44% of divers never made contact with the reef during their 5-minute observation period. Most divers (63%) never intentionally contacted the reef, and over half (53%) never accidentally contacted the reef. Just 15 divers (2.7% of all observed divers) accounted for a third of all intentional contacts. A third of accidental contacts were attributed to just 23 divers (4% of all observed divers), and three individuals were on both lists. Since a very small percentage of divers are causing the most direct impact to the reef, identification and targeted intervention for high-contact divers could enable a significant reduction in damage to reefs.

A total of 45 coral colonies were noticeably and immediately damaged by diver contact, accounting for 1.6% of all observed contacts. Two types of damage were observed: coral breakages (93%) and heavy sediment clouds deposited onto coral colonies (7%). Most breakages were accidental (71%). Accidental breakages were caused mostly by fins (87%) and other gear (10%) such as dangling gauges. Half of all intentional breakages were caused by divers' hands in apparent attempts to see what corals look like on the inside. The remaining half of intentional breakages were caused by divers intentionally kneeling, standing, or sitting on the substrate, usually to take photos. While the reef contact was intentional, however, it was not apparent in these cases that the divers intended to harm the corals.

3.2 Coral health surveys

3.2.1 Community composition

Along the 20 x 1 m belt transects, 4199 individual coral colonies comprising 32 genera and 71 species were recorded. Two species of octocorals (*Heliopora coerulea* and *Sinularia sp.*) corals were recorded. The most abundant genus was *Porites*, accounting for 76% of all recorded colonies (see

Appendix 2 for counts of all genera and species by site). *Porites rus* was the most common species (60%) and was observed on every transect. Other common species included *Platygyra pini*, *Pocillopora damicornis, Leptastrea purpurea, Leptoria phrygia*, *Goniastrea retiformis,* and *Diploastrea heliopora*. *Porites rus* was the dominant species in Apra Harbor, accounting for 92-97% of all colonies recorded at inner-harbor sites (Figure 5). The pair of sites located outside Apra Harbor, Amphitheater and Blue & White, were much more diverse, and these sites were also less dominated by *P. rus*.

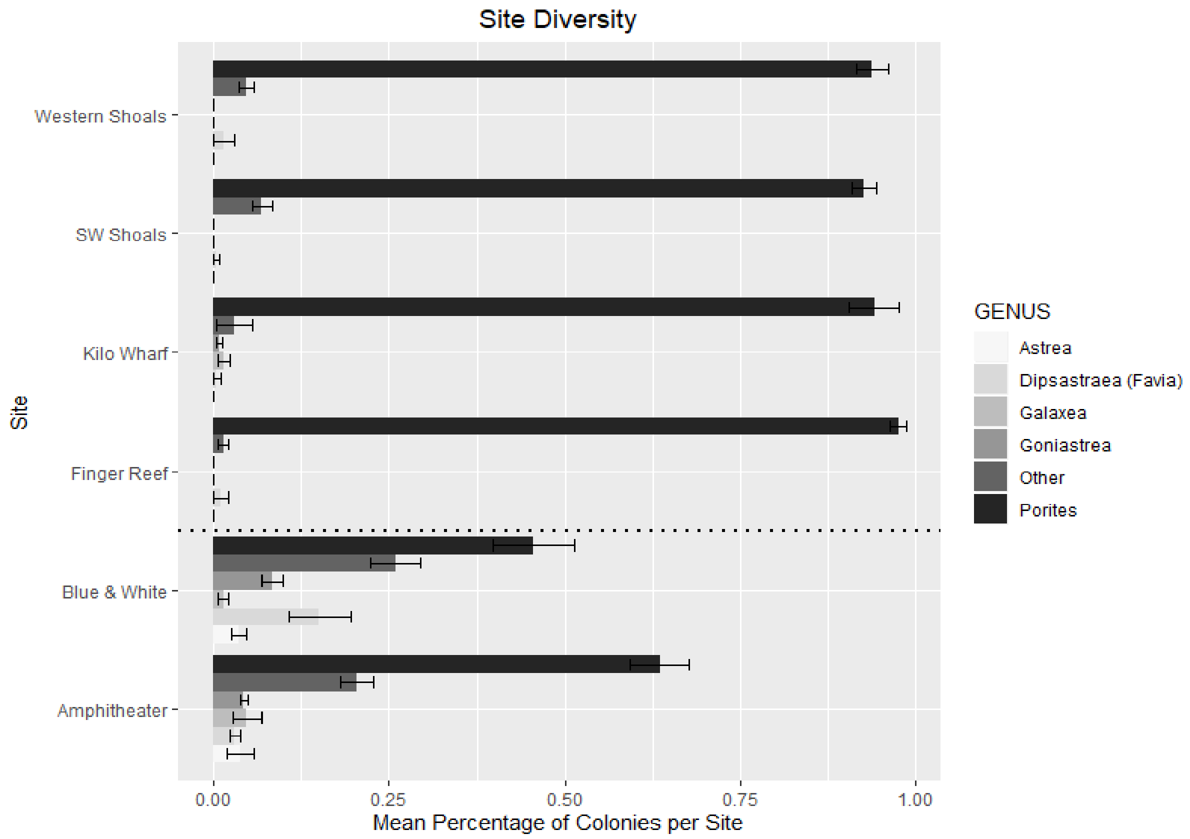

Figure 5. Bar plot of most common coral genera by site, averaged over all transects. The five most common genera are displayed, with all other genera grouped into the "Other" category.

3.2.2 Benthic cover

Live hard coral cover was highest in shallow waters at sites within Apra Harbor (Figure 6). Coral cover across the pairs of sites varied significantly by depth and location, but not by frequency of diving activity (Table 6). Site pair ID was tested but because there were no significant differences between the two pairs of inner harbor sites, this variable was found to be perfectly covariate with location and so it was dropped from this analysis. The sites within the harbor had higher coral cover in shallow water, but one of the outer harbor sites (Amphitheater) had lower coral cover in shallow water, resulting in an interaction between location and depth.

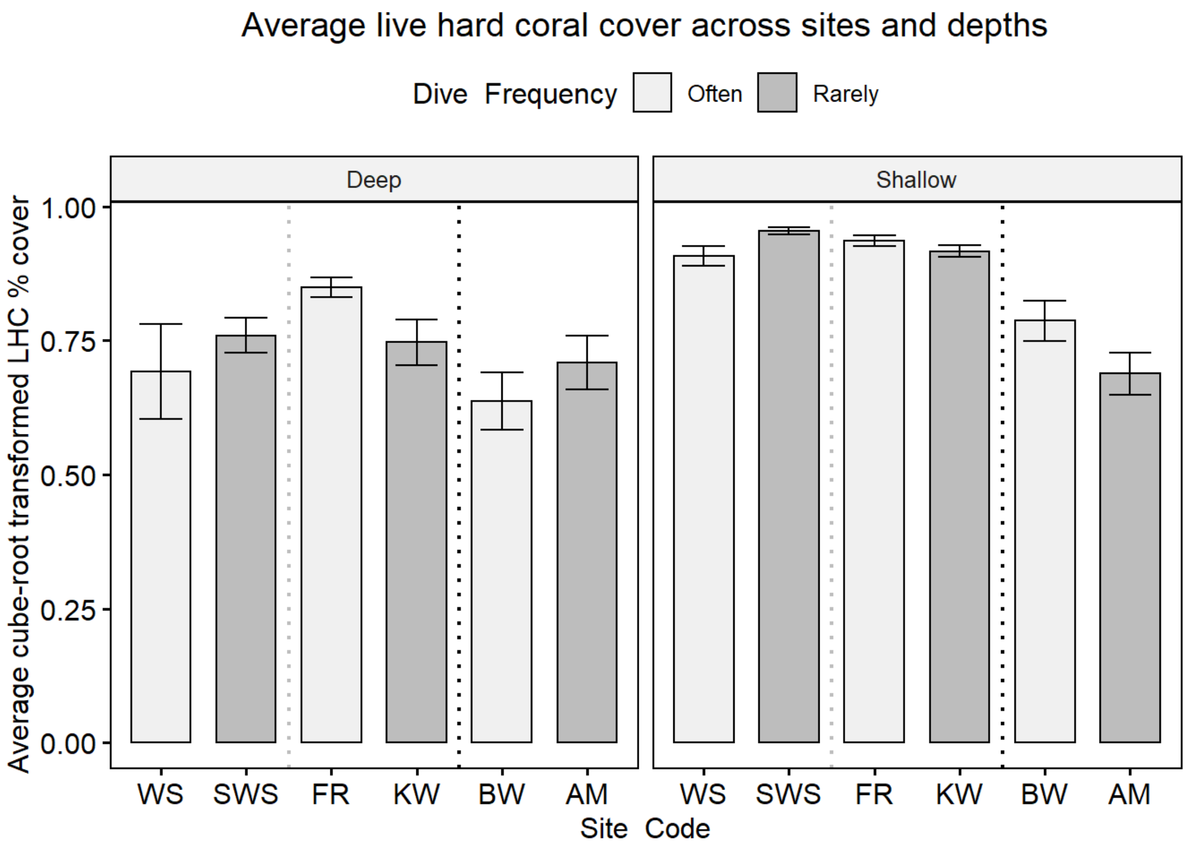

Figure 6. Average cube root transformed percent live hard coral cover across sites and depths. Site codes: WS = Western Shoals, SWS = Southwestern Shoals, FR = Finger Reef, KW = Kilo Wharf, BW = Blue & White, AM = Amphitheater.

Table 6. Results of ANOVA of cube root transformed percent live hard coral cover.

Variable	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Pair ID	***2***	***0.21779***	***0.1089***	***16.397***	***8.66E-06***	***
Dive Frequency	1	0.0004	0.0004	0.06	0.8085	
Depth	***1***	***0.21131***	***0.21131***	***31.818***	***2.10E-06***	***
Site	2	0.02815	0.01407	2.119	0.1349	
Pair ID:Depth	2	0.03974	0.01987	2.992	0.0628	
Dive Frequency:Depth	1	0.00385	0.00385	0.58	0.4511	
Depth:Site	2	0.0327	0.01635	2.462	0.0995	
Residuals	36	0.23908	0.00664			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Shapiro-Wilk normality test of residuals:
W = 0.97171, p-value = 0.2949

Combined cover of algae (including fleshy macroalgae, crustose coralline algae, cyanobacteria, and red filamentous algae) was much higher at sites within the harbor than sites outside the harbor (Figure 7). Dive frequency was a significant factor, with *often dived* sites having lower algal cover than *rarely dived* sites. The two pairs of inner harbor sites were significantly different, so both site pair ID and location were included in the ANOVA model (Table 7). In addition to site pair ID and location, depth was also a significant factor, with algae cover generally much lower on the shallow transects. However, Amphitheater bucks the trend again with higher algal cover in shallow waters, which produced an interaction effect between location and depth.

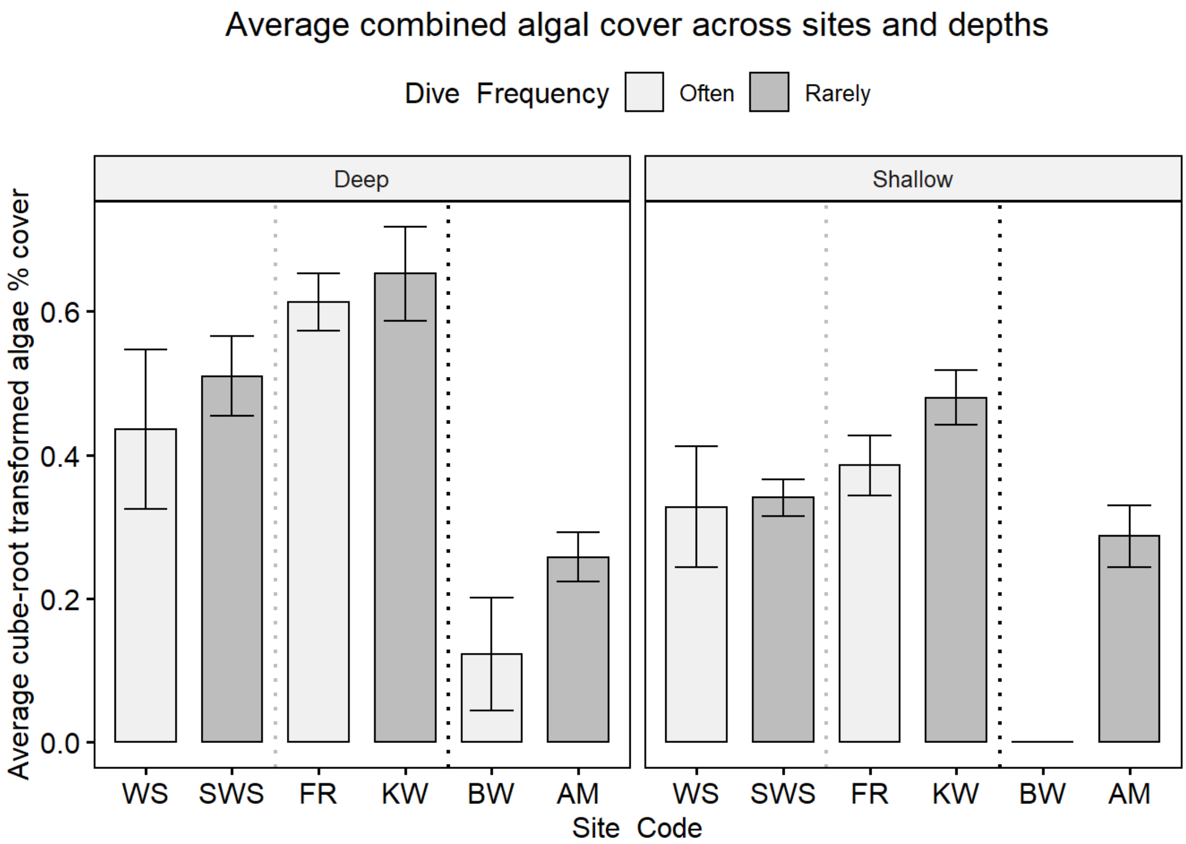

Figure 7. Average cube root transformed percent algal cover across sites and depths. Site codes: WS = Western Shoals, SWS = Southwestern Shoals, FR = Finger Reef, KW = Kilo Wharf, BW = Blue & White, AM = Amphitheater.

Table 7. Results of ANOVA of cube root transformed percent algal cover.

Variable	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Location	***1***	**0.7069**	**0.7069**	**47.018**	**5.06E-08**	*******
Pair ID	***1***	***0.134***	***0.134***	***8.911***	***0.00507***	******
Dive Frequency	***1***	***0.1198***	***0.1198***	***7.967***	***0.00771***	******
Depth	***1***	***0.1337***	***0.1337***	***8.892***	***0.00511***	******
Site	2	0.0489	0.0244	1.625	0.21108	
Location:Depth	***1***	***0.0972***	***0.0972***	***6.465***	***0.01545***	*****
Pair ID:Depth	1	0.0075	0.0075	0.499	0.48441	
Dive Frequency:Depth	1	0.0013	0.0013	0.089	0.76674	
Depth:Site	2	0.0104	0.0052	0.345	0.71079	
Residuals	36	0.5412	0.015			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Shapiro-Wilk normality test of residuals:
W = 0.96707, p-value = 0.1943

Sponge cover was nearly nonexistent at sites outside the harbor but accounting for about 10% of overall (non-transformed) cover at Southwestern Shoals. Dive frequency was a significant variable, with *rarely dived* sites exhibited higher sponge cover than *often dived* sites (**Table 8**). Other significant variables in this analysis were location, site pair ID, and depth. Most sites had lower sponge cover in shallow water, but Finger Reef had higher sponge cover in the shallows, which accounts for the interaction effect between site and depth in this analysis. These data did not meet the assumption of normal distribution of error (see Shapiro-Wilk results in **Table 8**), but as ANOVA is fairly robust to nonparametric data, I have included the results.

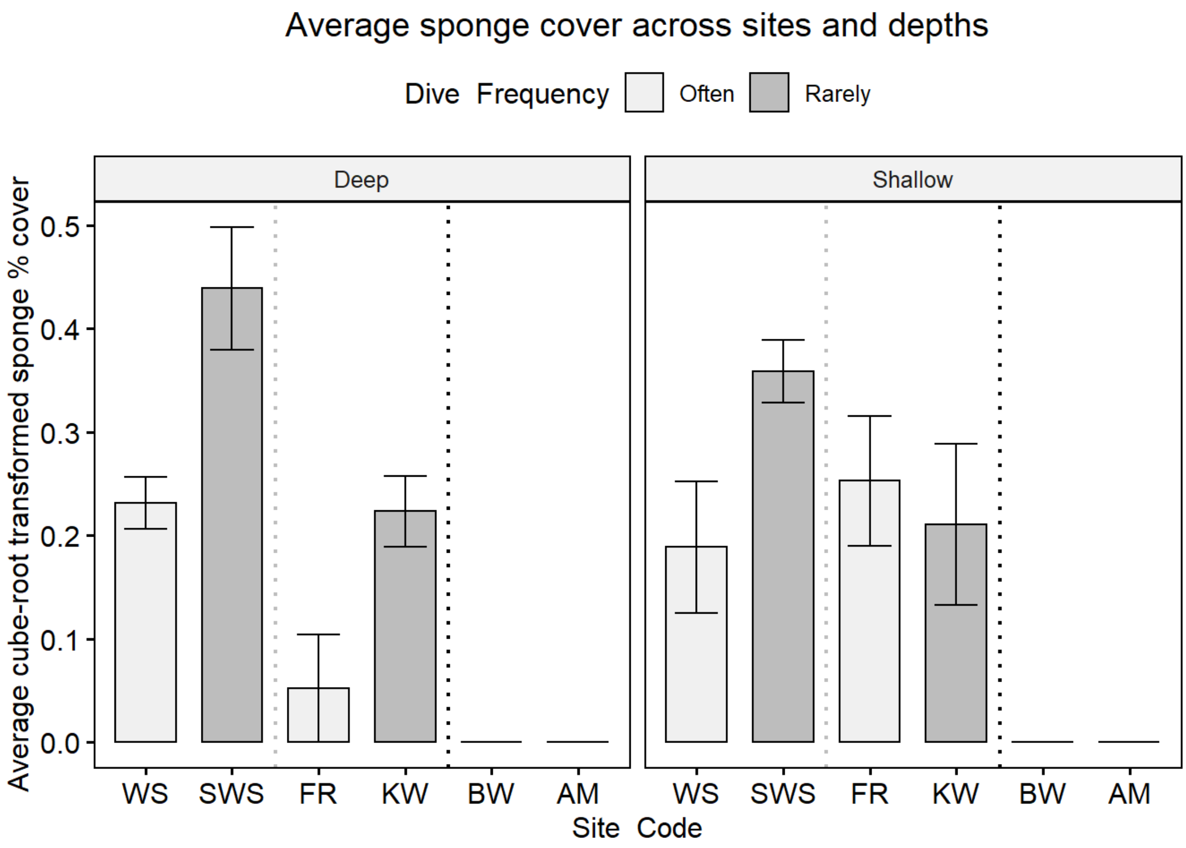

Figure 8. Average cube root transformed percent sponge cover across sites and depths. Site codes: WS = Western Shoals, SWS = Southwestern Shoals, FR = Finger Reef, KW = Kilo Wharf, BW = Blue & White, AM = Amphitheater.

Table 8. Results of ANOVA of cube root transformed percent sponge cover.

Variable	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Location	***1***	***0.6383***	***0.6383***	***83.247***	***6.78E-11***	*****
Dive Frequency	***1***	***0.0857***	***0.0857***	***11.173***	***0.001946***	****
Depth	1	0.0014	0.0014	0.186	0.668917	
Site	***3***	***0.1884***	***0.0628***	***8.192***	***0.000276***	*****
Location:Depth	1	0.0007	0.0007	0.093	0.762212	
Dive Frequency:Depth	1	0.0211	0.0211	2.751	0.105885	
Depth:Site	***3***	***0.0744***	***0.0248***	***3.233***	***0.033511***	***
Residuals	36	0.27373	0.0076			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Shapiro-Wilk normality test of residuals:
W = 0.94002, p-value = 0.01625

3.2.3 Health impacts

Breakage was significantly more prevalent at the *often dived* sites than *rarely dived* sites for two of the three pairs of sites (**Table 9**). There were no significant differences in breakage between Western Shoals and Southwestern shoals. Kilo Wharf, a *rarely dived* site, had significantly more tissue loss than its paired *often dived* site Finger Reef. There were no significant differences in combined health impacts (including sponge overgrowth, white syndrome, bleaching, corallivore predation, and macroalgal overgrowth) between *often dived* and *rarely dived* sites.

Table 9. Mean percentage of total colonies affected by health impacts by site.

Health Impact	Amphi-theater	Blue & White	Kilo Wharf	Finger Reef	SW Shoals	Western Shoals
Breakage	0.18%	4.08%	5.03%	30.15%	11.49%	10.19%
	p = 0.026		p = 0.0007		p = 0.958	
Tissue loss	20.07%	14.60%	28.59%	6.70%	3.13%	3.73%
	p = 0.271		p = 0.0007		p = 0.958	
Any health impact	38.44%	34.42%	59.59%	58.86%	36.27%	29.16%
	p = 0.506		p = 0.958		p = 0.958	

Thirty-nine percent of all colonies were afflicted by at least one health impact. Tissue loss (previous partial mortality where the cause is not discernable) was the most common, affecting 12% of all colonies. Breakage was the next most common impact, affecting 9% of colonies, followed by white syndrome (6%), macroalgal overgrowth (6%), and sponge overgrowth (4%). Bleaching affected just 1% of all colonies. Excluding coral species for which 5 or fewer colonies were observed, the average percentage of colonies afflicted by any health impact was 24%. Some *Porites* species were impacted more, particularly *Porites rus* and massive *Porites* colonies.

Size was a significant factor for health impacts, both overall ($p < 2.00E-172$) and pairwise between each size class ($p < 0.003$ or smaller). Most colonies were in size class 1 (48%) or size class 2 (30%), and 63% of all species observed were limited to these two size classes. Nearly all (97%) colonies in size classes 5 and 6 were *Porites rus* colonies. A post-hoc test (simple linear regression, $r = 0.41$, $p = 0$) revealed that affliction by any health impact was strongly correlated to colony size (**Table 10**).

Table 10. Proportion of colonies with health impacts by size.

Size class	Colony Count	Percent afflicted by any health impact
1	2015	23.42%
2	1264	37.34%
3	555	67.39%
4	218	77.98%
5	117	94.87%
6	30	100.00%
Overall	**4199**	**38.79%**

3.3 Predictors of high-impact divers

A correlation plot revealed strong correlations between several predictors of high-impact divers (Figure 9). Several correlations are expected due to the 'dummy variable' nature of regression analysis; for example, "Site type: Porites-dominant" is a subtype of "Site type: Coral-dominant," so these two predictors are strongly and positively correlated. Similarly, certification level was strongly positively correlated with lifetime dives and dives last year. Residence in an Asian country was negatively correlated with buoyancy control ability, dives last year, lifetime dives, certification level, and training last year. Residence in an Asian country was positively correlated with camera use and group size.

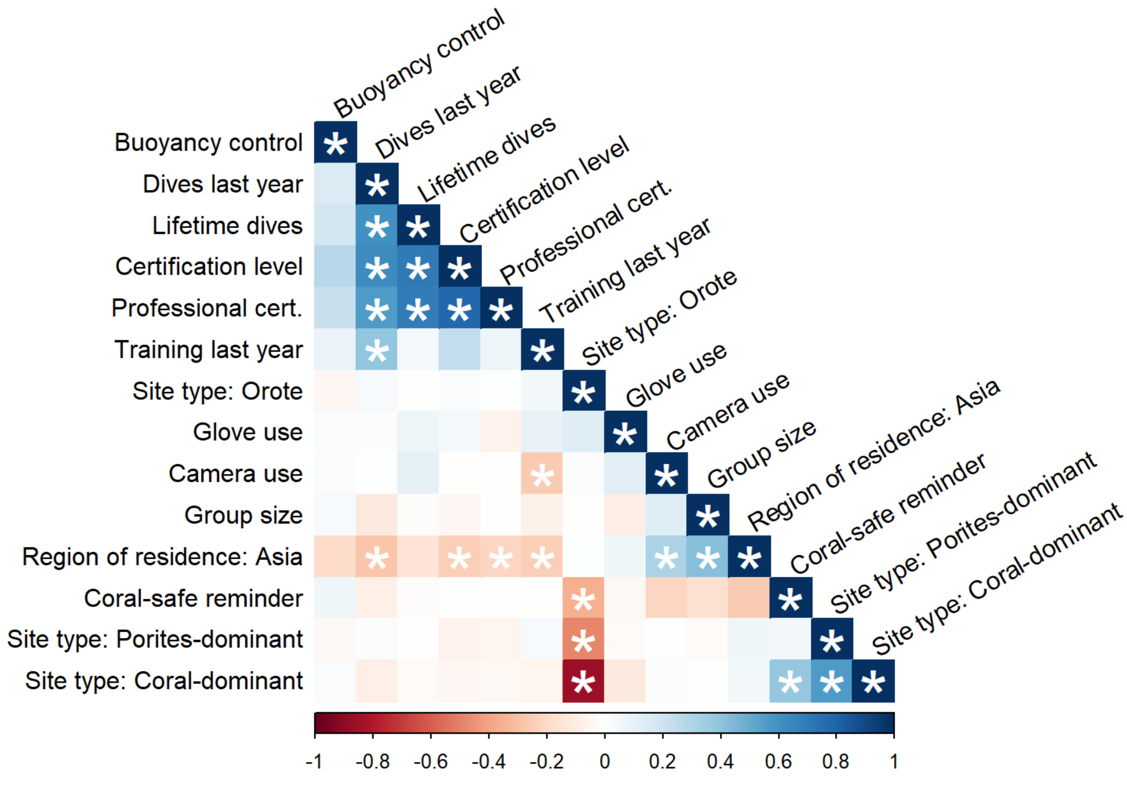

Figure 9. Correlation plot of predictors for high-impact divers. Stars denote significant ($p < 0.05$) correlations.

3.3.1 Guide/client correlation

Nineteen professionally guided groups of divers, containing a total of 20 guides and 57 clients, were observed throughout this study. The contact rates of guides and their clients were strongly and positively correlated (Figure 10). Correlations for intentional contacts were extremely high, both for contacts overall (r = 0.68, p < 0.0001) and for coral contacts specifically (r = 0.65, p < 0.0001). Correlations were also high for accidental contacts overall (r = 0.58, p < 0.001) and for coral contacts specifically (r = 0.49, p < 0.0001).

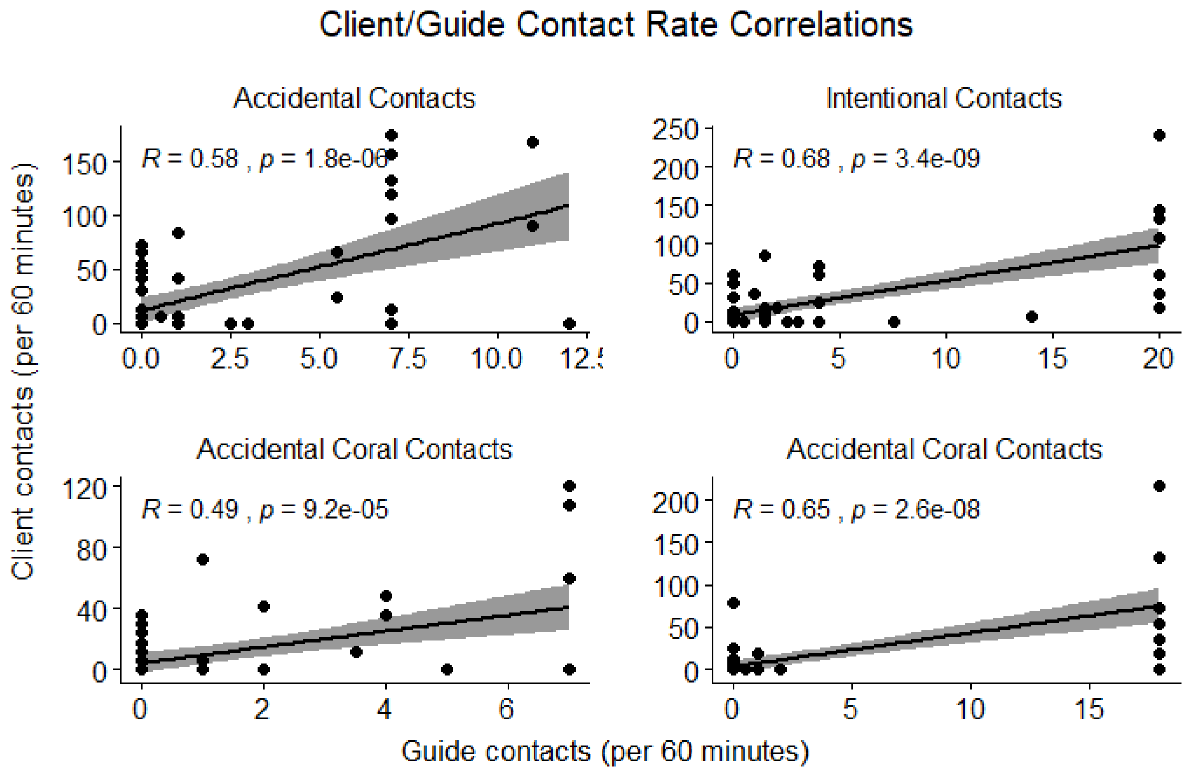

Figure 10. Correlations between guide and client contact rates.

3.3.2 Group size

Divers in larger groups made significantly more contacts individually than divers in smaller groups (Figure 11). Dive group sizes were binned into two classes: 2-4 divers, and 5-8 divers. Unusual size groups (solo divers and groups of 9 or more divers) were excluded from this analysis due to low numbers. Individually, divers in larger groups made roughly twice as many contacts as divers in smaller groups (Table 25).

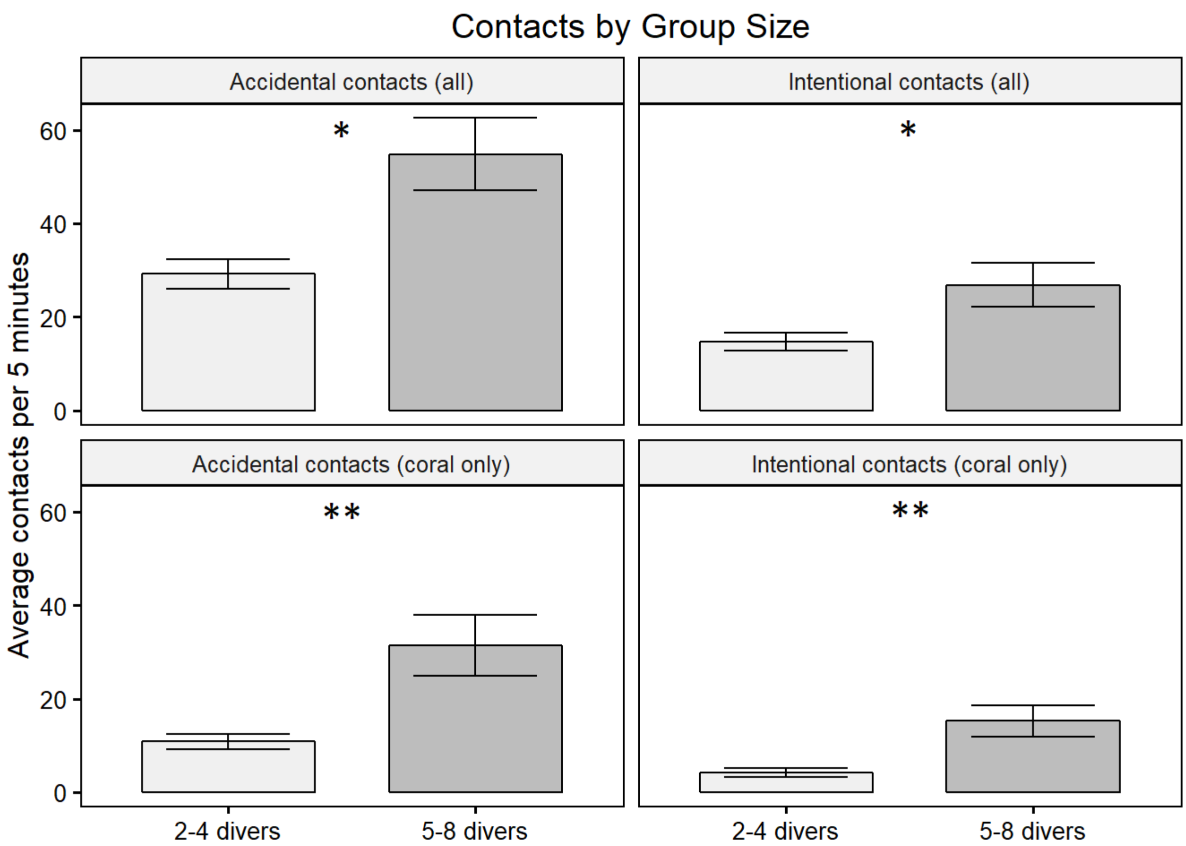

Figure 11. Average contact rates by dive group size. (Stars denote significance: * = $p < 0.05$, ** = $p < 0.001$, and *** = $p < 0.0001$.)

3.3.3 Site Type

There were significant differences in the contact rates between different site types for both accidental (Kruskal-Wallis test, $p < 0.001$) and intentional ($p < 0.02$) contacts. Divers exhibited the highest intentional and accidental contact rates at pavement-dominated sites and wreck sites, and the lowest contact rates at shallow sites around the breakwater (Figure 12). Diver contacts with live hard coral were significantly lower at pavement-dominated and wreck sites, but this was expected due to the much lower coral cover at these sites; there is simply less coral to touch.

Coral-dominated sites were further divided into two subtypes: *Porites*-dominant and non-*Porites*-dominant. Many of Guam's reefs, particularly those inside Apra Harbor, are dominated by plate- and column-forming *Porites rus* colonies. Other sites, such as those outside the breakwater, have more diverse coral communities. Divers made more contacts of all types at *Porites*-dominated sites, and differences in accidental contacts with corals between the two subtypes were significant (Kruskal-Wallis test, $p < 0.005$), with divers making three times more contacts with coral at *Porites*-dominant sites. Despite a clear trend of divers making more contacts at *Porites*-dominant sites, no significant differences were found for other contact categories between the coral-dominated site subtypes.

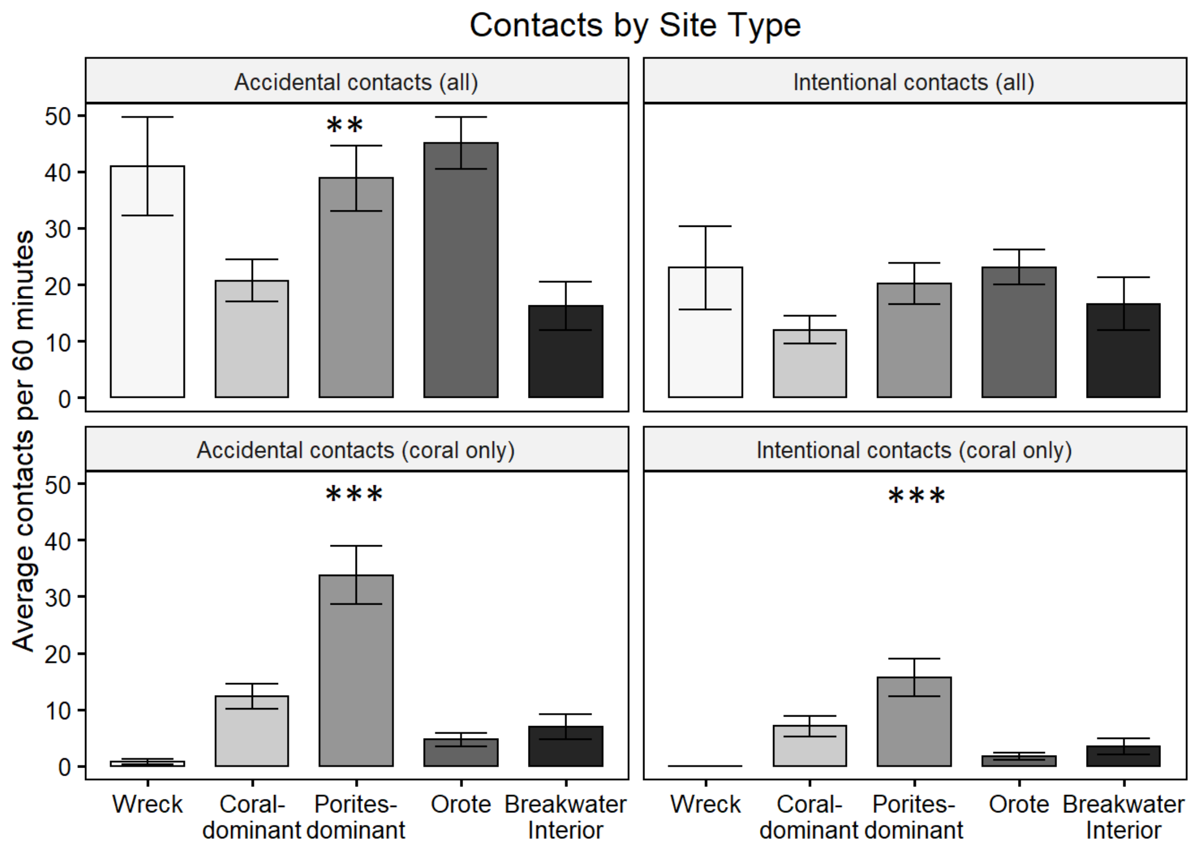

Figure 12. Average contact rates by site type. (Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

3.3.4 Demographic predictors

Male divers made more contacts than female divers, but these differences were not significant. Age, education level, employment status, marital status, diver certification level, and number of lifetime dives also did not produce significant differences. Professionally certified divers (instructors and divemasters) made significantly *more* intentional contacts overall ($p < 0.03$) than recreational divers, but (non-significantly) fewer accidental contacts. Region of residence was significant for all contact categories (Figure 13); divers who resided in Asian countries exhibited significantly higher contact rates in every contact type compared to divers from the United States/Hawaii and Guam residents (Table 20). Divers from Asian countries made up 36.5% of all observed divers but accounted for 53.6% of all contacts. (Note that “Asian” refers only to country of residence, not ethnicity.)

When given a coral-safe diving reminder, Guam resident divers exhibited a significant decrease in both accidental and intentional contacts. While visitors from both Asian countries and the United States/Hawaii also made fewer contacts when given a coral-safe diving reminder, only the declines in accidental contacts were significant.

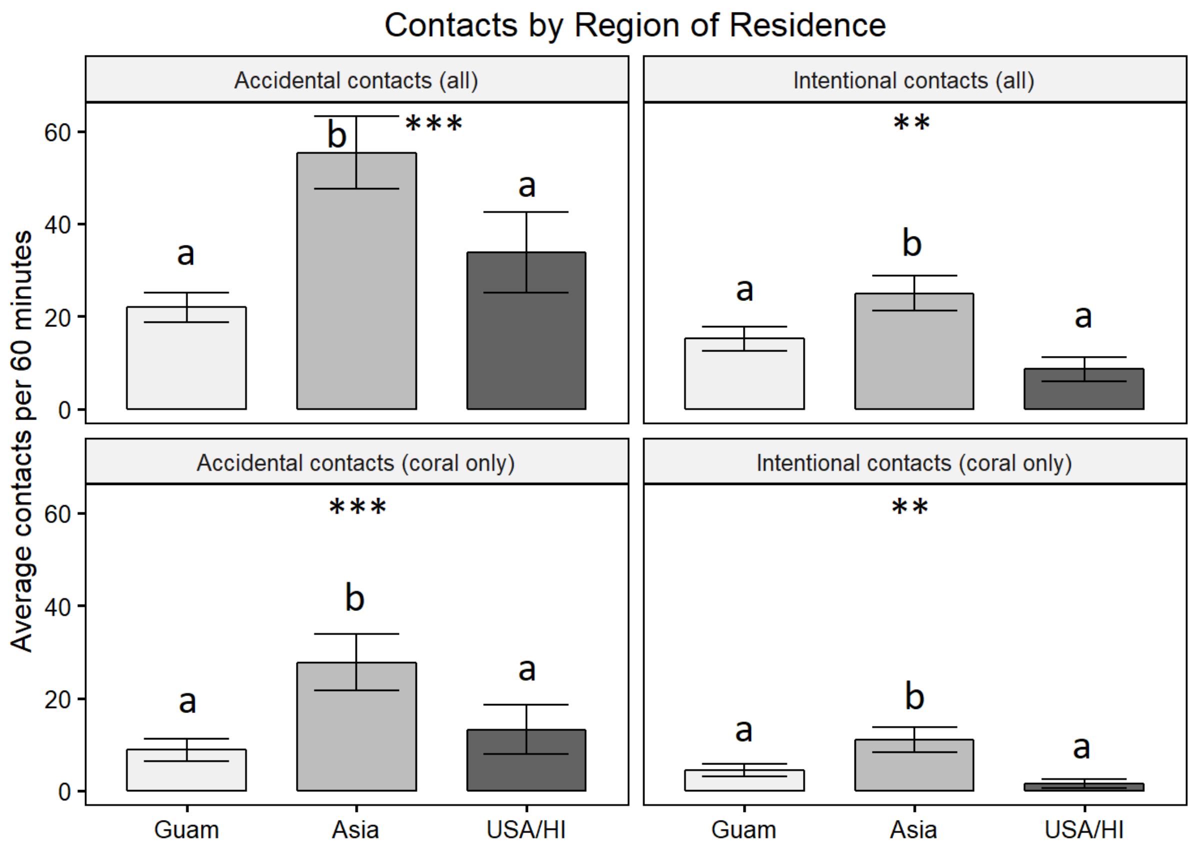

Figure 13. Contact rates by region of residence. (Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

3.3.5 Diving experience, activity, and training

Divers were asked to report the number of dives they had made within their lifetime, and while there were no significant differences in contact rates between groups, some interesting trends emerged. As diving experience increased, average accidental contacts (both overall and for corals specifically) tended to decline, while intentional contacts overall (but not for coral specifically) tended to increase. However, divers who reported 21-50 lifetime dives made the fewest contacts for all categories except intentional contacts with coral, in which they made the second-fewest contacts. The least experienced divers (1-20 dives) made the fewest average intentional contacts with coral (Figure 14). This trend was closely mirrored for contacts by certification level.

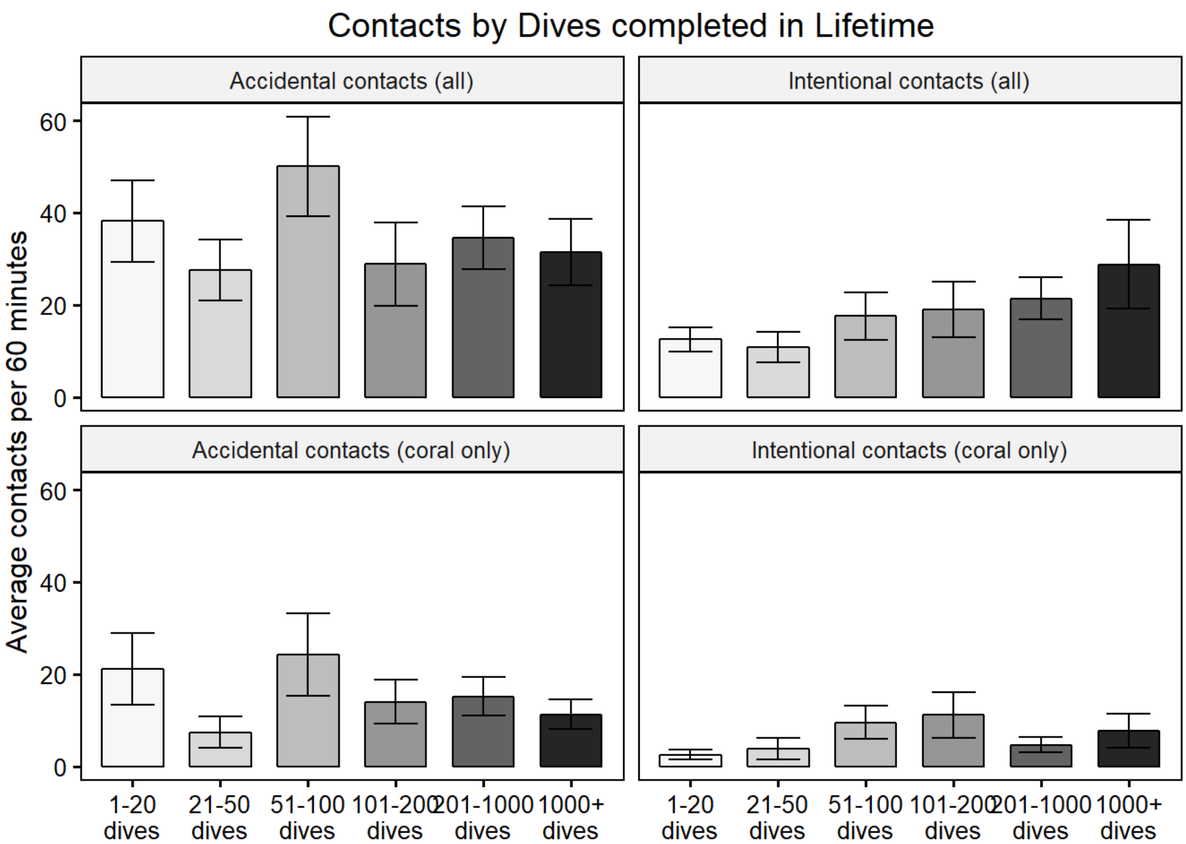

Figure 14. Diver contact rates by number of lifetime dives.

Divers were also asked to report the number of dives they had made within the previous year. While there were no significant differences between groups, intentional contacts tended to rise with more diving activity (Figure 15).

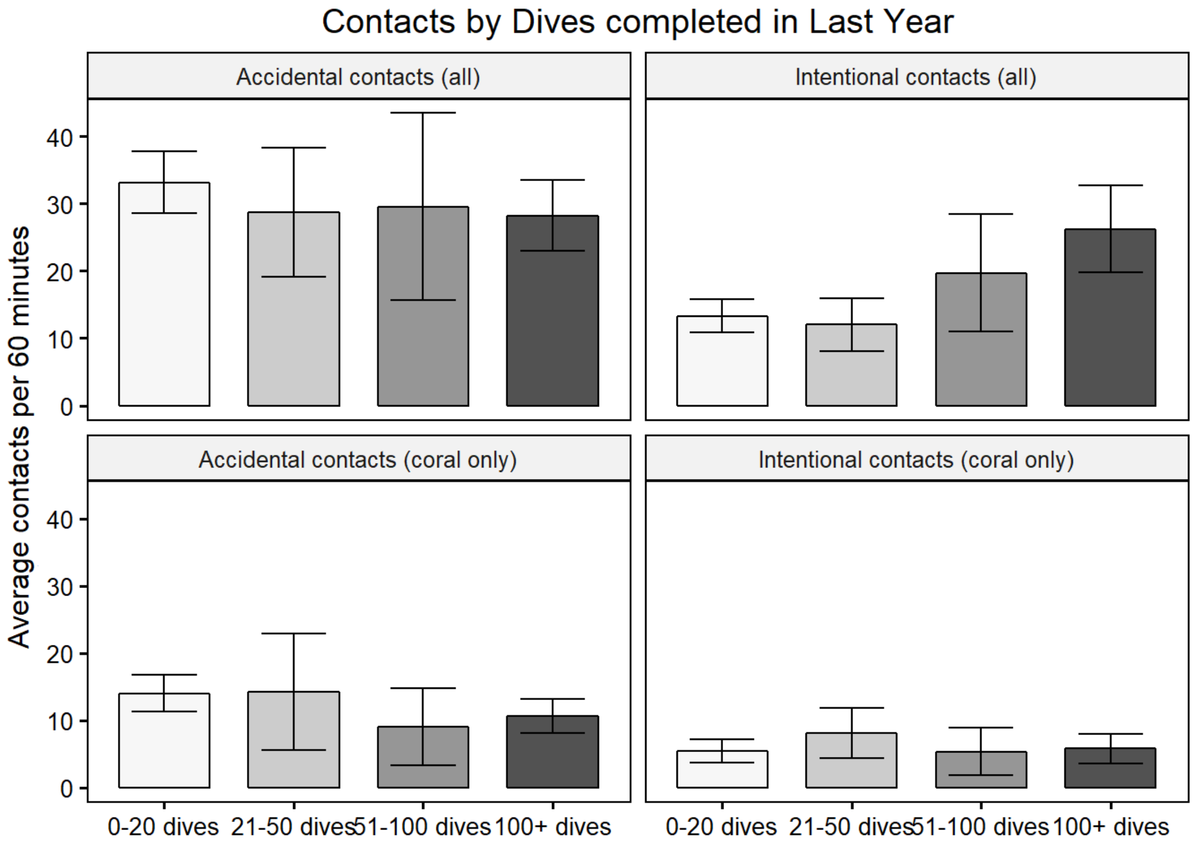

Figure 15. Diver contact rates by dives completed in the last year.

Finally, divers were asked whether they had taken any advanced dive training (such as PADI Advanced Open-Water Diver or PADI Rescue Diver) or specialty courses (e.g. Underwater Photography, Peak Performance Buoyancy, etc.) within the last year. Divers who obtained their basic open-water certification in the previous year were not included in this analysis. Among divers who had been open-water certified for longer than one year, 36% reported taking advanced dive training and/or a specialty class within the last year, and these divers made significantly fewer accidental contacts than divers who took no training/courses (Figure 16 and Table 21).

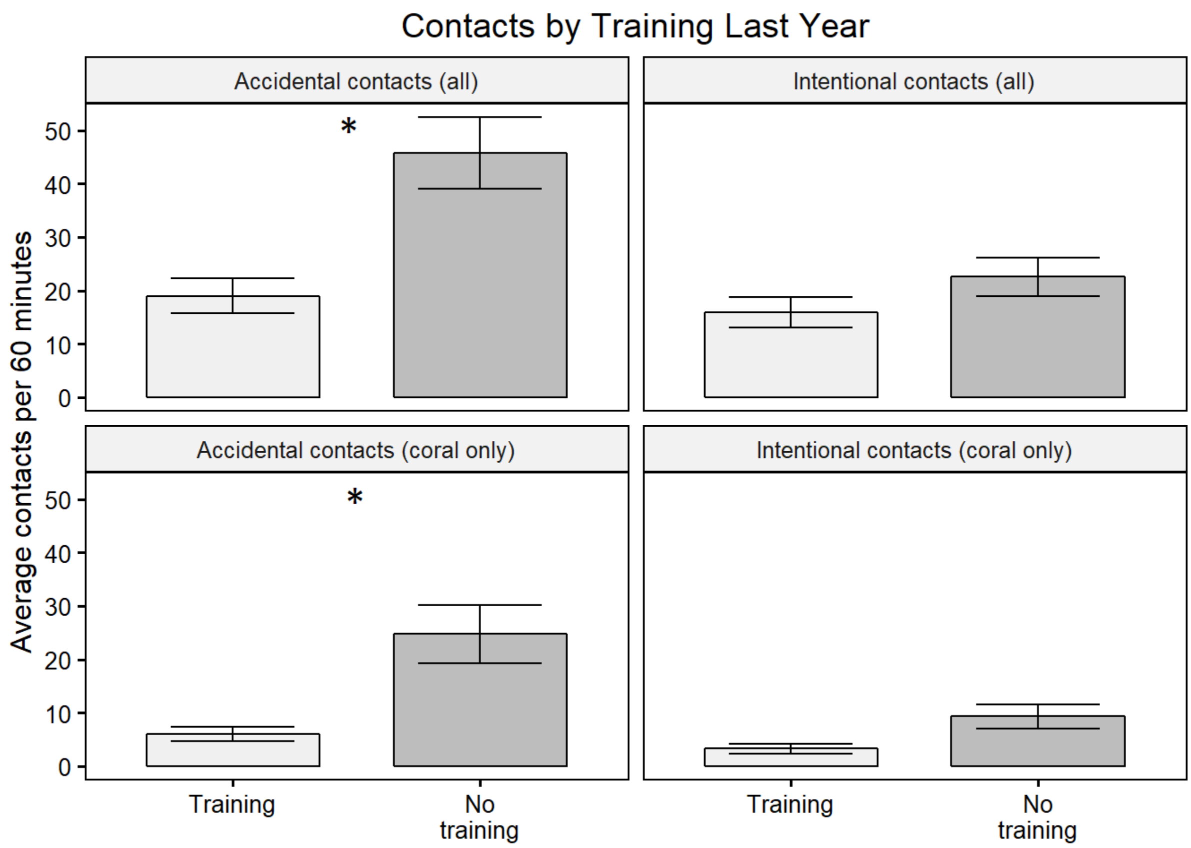

Figure 16. Average contact rates by training within the last year. (Stars denote significance: * = $p < 0.05$, ** = $p < 0.001$, and *** = $p < 0.0001$.)

3.3.6 Cameras

Most divers (59%) did not use cameras during their dives. Camera users were split evenly between GoPro-style cameras (49%) and point-and-shoot cameras (45%), with only a very small subset (6%) using more expensive DSLR cameras. Divers from Asian countries used cameras significantly more often than divers from the United States/Hawaii or Guam (Chi squared test, $\chi^2 = 10.949$, df = 2, $p < 0.005$), with more than half (51%) of divers from Asian countries using cameras, compared to 35% of Guam residents and 29% of visitors from the United States/Hawaii. Asian camera users overwhelmingly (72%) preferred using point-and-shoot cameras, while GoPro-style cameras were favored by Guam residents (65%) and visitors from the United States/Hawaii (80%).

Despite comprising just 37% of all observed divers, camera users made 46% of all accidental contacts 43% of all intentional contacts. Camera users also made more than their fair share of contacts with live coral specifically, accounting for 49% of accidental coral contacts and 54% of intentional coral contacts. There were no significant differences in contact rates between DSLR and point-and-shoot users, nor were there significant differences between GoPro-style camera users and divers without cameras

Table 22).

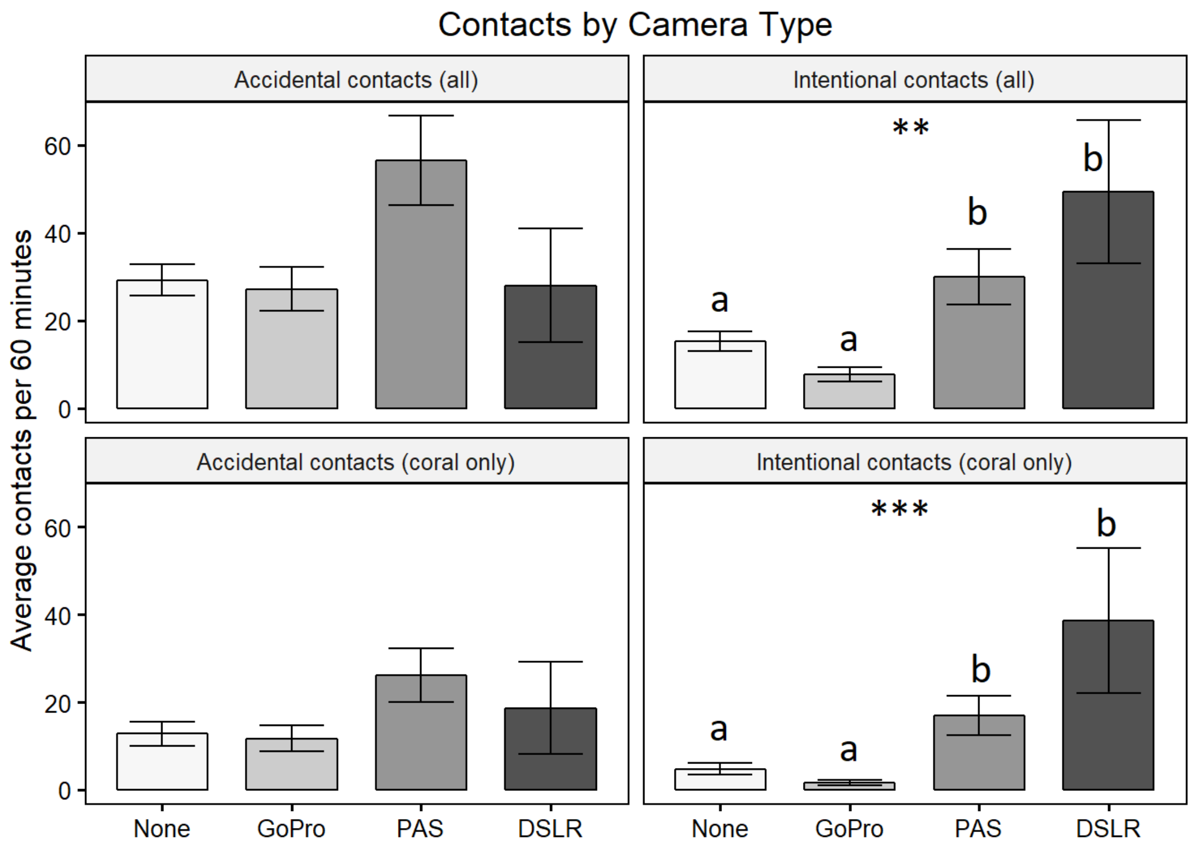

Figure 17. Average contact rates by camera type. (Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

When given a coral-safe diving reminder, divers without cameras made significantly fewer intentional ($p = 0.008$) and accidental ($p = 0.002$) contacts. Divers with point-and-shoot and GoPro-style cameras made significantly fewer accidental contacts ($p = 0.049$), but the reduction in intentional contacts was not significant. DLSR camera users could not be tested due to the small sample size.

3.3.7 Gloves

Most divers (77%) did not wear gloves, and there were no significant differences in proportions of divers using gloves based on region of residence or gender (Chi squared test, $p > 0.05$). Overall, divers with gloves made significantly more contacts than divers without gloves (Figure 18). Divers who wore gloves made 40% more accidental contacts and 44% more intentional contacts than divers who did not wear gloves. For coral contacts specifically, divers with gloves made 32% more accidental contacts and 53% more intentional contacts than divers without gloves. These differences were significant for all but accidental contacts with corals (Table 23). However, this trend was driven solely by divers from Asian countries; divers from the United States/Hawaii exhibited no significant differences with or without gloves, and Guam residents tended to make more contacts *without* gloves (although these differences were also not significant.) Divers from Asian countries who wore gloves made nearly three times as many contacts with live hard corals as divers from Asian countries without gloves, and contact rates were twice as high for all other contact categories. Divers from Asian countries who wore gloves accounted for just 9% of all observed divers but were responsible for 24% of all accidental contacts and 21% of all intentional contacts.

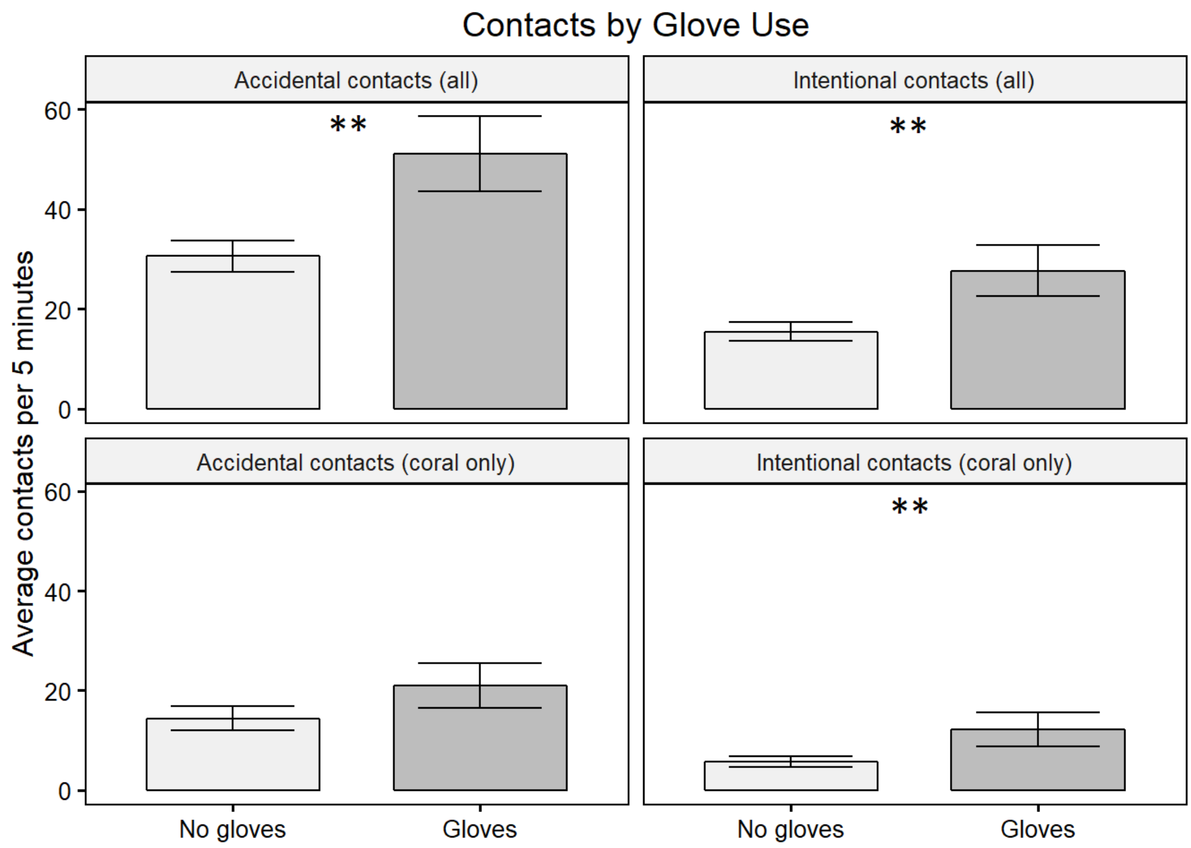

Figure 18. Average contact rates by glove use. Divers with gloves accounted for 25% of observed divers but made a third of all contacts. (Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

3.3.8 Buoyancy Control

Most divers (76%) exhibited good buoyancy control, and few (4%) exhibited poor buoyancy control. Accidental contact rates varied significantly by buoyancy control level, but intentional contacts did not (Table 24). Buoyancy control rating varied significantly by gender, with male divers exhibiting better buoyancy control than female divers (Chi square test, χ^2= 18.819, df = 2, p < 0.0001). Eighty-two percent of male divers (n = 215) were rated as having "good" buoyancy control, while 66% of female divers (n = 123) were rated as "good." Conversely, 9% of female divers were rated as having "poor" buoyancy control, while just 2% of males were given this rating.

Buoyancy control also varied significantly by region of residence, with divers from Asian countries exhibiting poor buoyancy control more often than divers from Guam or the United States/Hawaii (Figure 19). Divers from Asian countries were more than three times more likely to be rated "poor" than divers from Guam or the United States/Hawaii (Table 11).

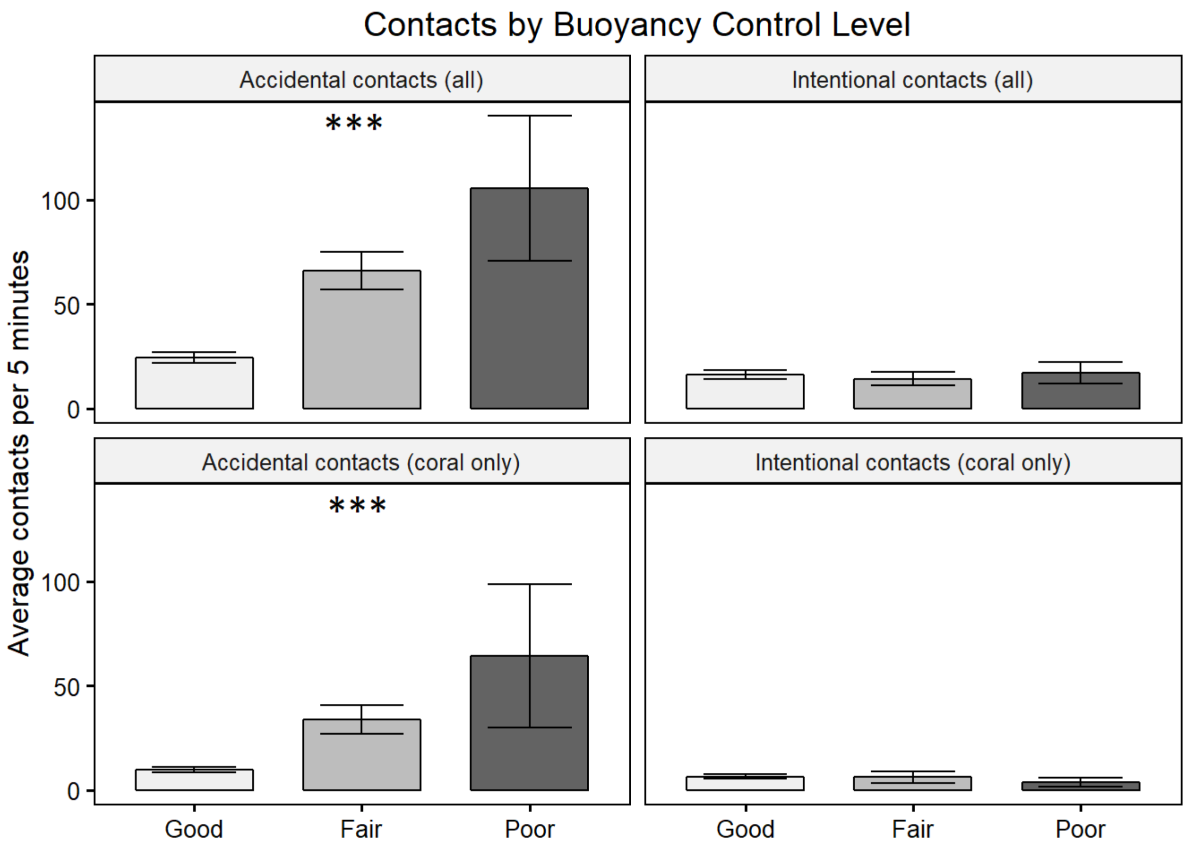

Figure 19. Average contact rates by observed buoyancy control level. (Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 11. Buoyancy control levels varied significantly by region of residence.

	Buoyancy Control Level		
Region of Residence	Good	Fair	Poor
Guam	83%	14%	3%
USA/HI	67%	31%	2%
Asia	62%	29%	9%

Chi square test, χ^2= 19.529, df = 4, $p < 0.001$

3.3.9 First vs. second dive

A pairwise test was conducted to compare contact rates between the first and second dives for control-group divers who were observed on both dives. Pairwise testing revealed no significant differences in accidental contact rates (Wilcoxon signed-rank test, $p = 0.54$, $n = 85$) or intentional contact rates (Wilcoxon signed-rank test, $p = 0.27$, $n = 85$) between divers' first and second dives.

3.3.10 Stepwise regression analysis

Stepwise regression analysis revealed several significant predictors of high-impact divers. Predictor variables tested in this analysis are listed in (Table 12). Only predictors that were found to be significant in single-factor analysis were included. As the focus of this analysis was to assist diving professionals in identifying divers who require more supervision *before* entering the water, buoyancy control was not included in the regression models. Roughly half of all observations were missing data (often because a diver did not complete a questionnaire) and had to be dropped from the analysis. A total of 309 observations were included for regression analysis.

Table 12. Predictor variables tested in stepwise regression analysis.

Ordinal Variables	Nominal Variables	Continuous Variables
Certification Level	**Site Type**	**Group Size**
Open Water	Coral-dominant	
Advanced Open Water	Breakwater	
Rescue/Master Diver	Pavement	
Divemaster/Instructor	Shipwreck/WWII Wreckage	
Lifetime Dives	**Region of Residence**	
1-100 dives	Guam	
101-1000 dives	USA/HI	
1000+ dives	Asia	
Dives Last Year	**Camera**	
1-20 dives	None/GoPro-style	
21-50 dives	DSLR/Point-and-shoot	
51-100 dives		
100+ dives	**Gender**	
	Male	
	Female	
	Gloves	
	Gloves	
	No gloves	
	Coral-safe diving reminder	
	Reminder	
	No reminder	

Positively correlated predictors for accidental contacts included the use of gloves and a basic open water certification (Table 13). Negatively correlated predictors for accidental contacts included being a Guam resident, receiving a coral-safe diving reminder, making fewer dives in the last year, and diving at a coral-dominated site. Diver who made more dives in the last year made more accidental contacts. Open water certification was the only certification level correlated with contact rates. Lifetime dives were not correlated with contacts. The model explains approximately 15% of variance in accidental diver contact rates.

Table 13. Results of stepwise regression analysis of accidental contacts.

Predictor Variable	Coefficient	Standardized Coefficient	Std. Error	t value	Pr(>|t|)	
(Intercept)	3.5334	0.0000	0.3853	9.17	< 2e-16	***
Gloves	0.3429	0.0761	0.2437	1.407	0.16049	
Coral-safe diving reminder	-0.8557	-0.2074	0.2481	-3.449	0.000644	***
Region of residence: Guam	-0.9024	-0.2223	0.2643	-3.415	0.000726	***
0-20 dives in last year	-1.186	-0.2913	0.3614	-3.281	0.001156	**
21-50 dives in last year	-0.8057	-0.1469	0.3829	-2.104	0.03618	*
51-100 dives in last year	-0.8765	-0.1376	0.4276	-2.05	0.041247	*
Certification level: open water	0.5313	0.1047	0.2993	1.775	0.076899	
Site type: coral-dominant	-0.4954	-0.1219	0.2372	-2.089	0.037579	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

Residual standard error: 1.867 on 300 degrees of freedom

Multiple R-squared: 0.1699, Adjusted R-squared: 0.1477

F-statistic: 7.673 on 8 and 300 DF, p-value: 2.362e-09

Intentional diver contacts were positively correlated with use of a DSLR or point-and-shoot camera, wearing gloves, making more than 50 dives in the last year, and diving at sites near the breakwater in Apra Harbor (Table 14). Negatively correlated predictors for intentional contacts included being a Guam resident, receiving a coral-safe diving reminder, making 50 or fewer dives in the last year, and diving at shipwreck/WWII wreckage sites.

Table 14. Results of stepwise regression analysis of intentional contacts.

Predictor Variable	Coefficient	Standardized Coefficient	Std. Error	t value	Pr(>|t|)	
(Intercept)	1.3363	0.0000	0.4944	2.703	0.00726	**
Site type: coral-dominant	0.9805	0.3003	0.4683	2.094	0.03714	*
Site type: breakwater	1.5129	0.1802	0.63	2.402	0.01694	*
Site type: pavement	1.1863	0.3522	0.4614	2.571	0.01063	*
1-100 lifetime dives	0.4523	0.1384	0.216	2.095	0.03706	*
Camera‡	0.3887	0.0948	0.2329	1.669	0.09621	
Gloves	0.6481	0.1791	0.2052	3.159	0.00175	**
0-20 dives in last year	-1.6891	-0.5165	0.3372	-5.009	9.40E-07	***
21-50 dives in last year	-1.6031	-0.3640	0.3431	-4.673	4.51E-06	***
51-100 dives in last year	-1.106	-0.2161	0.3628	-3.048	0.00251	**
Region of residence: Guam	-0.4543	-0.1393	0.2157	-2.106	0.03601	*
Coral-safe diving reminder	-0.4806	-0.1450	0.2052	-2.342	0.01985	*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Residual standard error: 1.495 on 297 degrees of freedom
Multiple R-squared: 0.183, Adjusted R-squared: 0.1528
F-statistic: 6.049 on 11 and 297 DF, p-value: 6.216e-09
‡ Camera use includes DSLR and point-and-shoot cameras, but not GoPro-style cameras.

3.4. Questionnaire results

3.4.1 Demographic description

Full demographic results are found in (Appendix 7). The majority of divers surveyed were male (60%) and younger than 40 years old (55%). Most divers were either married (55%) or single (38%). Divers ranged considerably in income level, with 30% reporting less than USD$50,000 and 31% reporting more than USD$100,000 annually. Divers were generally well-educated, with 67% holding a bachelor's degree or higher. Guam residents made up the majority of divers (48%), and more than half (56%) of Guam residents were active military servicemembers or their dependents. Divers from Asia were the second most populous group and were mostly (71%) from Japan. Visiting divers tended to be repeat visitors to Guam (62%) and generally planned to stay 4-7 days (61%).

3.4.2 Diving demographics

Full diving demographic results are found in Appendix 8. Most divers (81%) held recreational scuba certifications. Nearly half (47%) had been certified divers for 6 or more years, while 19% reported earning their basic open water certification within the last six months. Forty-one percent reported making 10 or fewer dives in the previous year, while 18% reported making more than 100 dives in the previous year. Diving experience ranged widely, with 42% reported more than 100 lifetime dives. Professionally certified divers (instructors or divemasters) made significantly more lifetime dives than recreational divers (Mann-Whitney U test, $p < 0.00001$). Professionally certified divers accounted for 80% of divers with more than 500 lifetime dives, and 97% of divers with more than 700 lifetime dives.

3.4.4 Questionnaire results by demographics

Diver responses to questionnaire items did not vary significantly by gender, age, or education level. Divers who reported annual incomes of US$100,000 or more were significantly more likely to agree with the statement "divers can hurt corals," but there were no significant differences for other statements.

Divers from Guam and the United States/Hawaii were generally more knowledgeable and more confident in their diving skills than divers from Asian countries (Figure 20). Divers from Asian countries rated themselves significantly ($p < 0.002$) lower on "I know a lot about coral reefs" than divers from Guam and the USA/HI. For the second statement, "White corals are healthy corals," divers from Asian countries were significantly ($p < 0.01$) more likely to agree with the statement than Guam residents. Most divers strongly disagreed with the statement "fish feeding is good for reefs," and there were no significant differences by region. Divers from the USA/HI and Guam residents were significantly ($p < 0.0001$) more likely to agree with the statement "scuba divers can hurt corals" than divers from Asian countries. Although divers from Asian countries were less likely to agree with the statement "I want to know more about coral reefs," overall interest in coral reef education was strong. On the statements "I am a skilled diver" and "I am skilled at controlling my buoyancy," divers from Asian countries rated themselves significantly lower than divers from the USA/HI, and both groups rated themselves significantly lower than Guam residents. These self-ratings were generally consistent with observational data (see section 3.10).

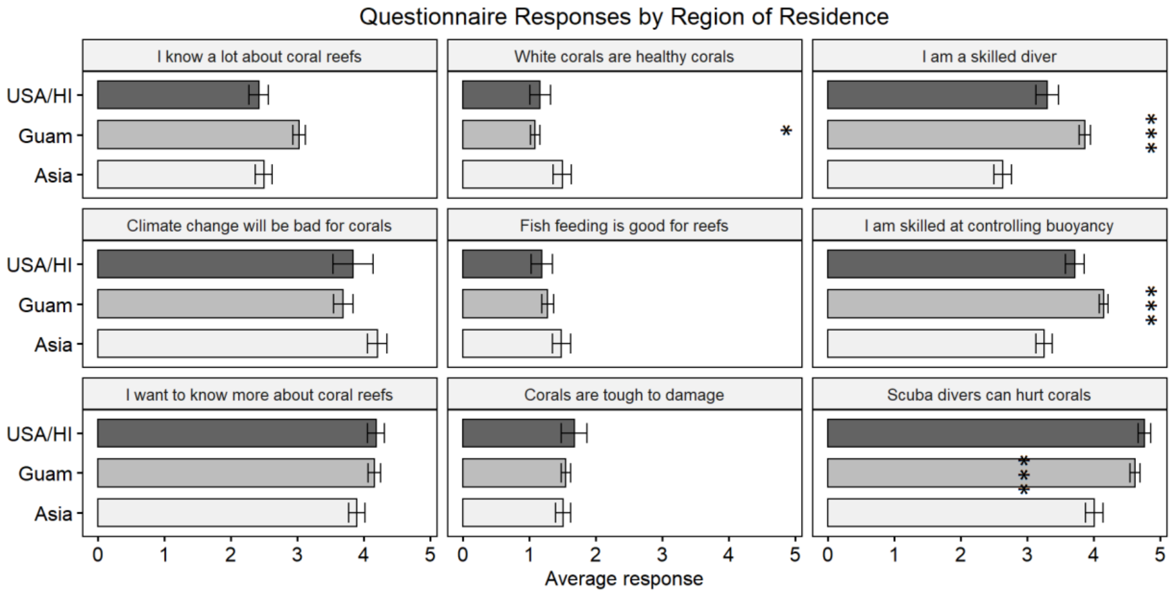

Figure 20. Average responses to questionnaire statements by region of residence.

Overall, few respondents selected “I don’t know” to questionnaire items, and these responses rarely accounted for more than 5% of total responses. However, many military servicemembers answered “I don’t know” to questionnaire items, sometimes accounting for more than 20% of answers. This skewed average responses, so results comparing Guam resident civilians to Guam resident military servicemembers and dependents are presented as percentages of total responses rather than averages. (Foreign military members and United States military servicemembers stationed elsewhere were not included in this analysis.) There were significant differences between civilians, active-duty military servicemembers, and military dependents for the statement “I know a lot about coral reefs” (Chi square test, $\chi^2 = 29.37$, df = 6, $p < 0.0001$). Civilians mostly (47%) agreed with the statement, while servicemembers generally (54%) disagreed, and most (42%) military dependents neither agreed nor disagreed. Answers also differed significantly for the statement “fish feeding is good for reefs,” with civilians much more likely to disagree (79%) than dependents (64%) or servicemembers (47%); many servicemembers (39%) answered that they did not know ($\chi^2 = 19.466$, df = 6, $p < 0.004$). Most civilians (89%), dependents (81%), and servicemembers

(64%) disagreed with the statement “white corals are healthy corals,” but servicemembers were more likely to answer that they did not know (28%), compared to 16% of dependents and just 8% of civilians ($\chi^2 = 16.28$, df = 6, $p < 0.02$). More than 75% of divers in all three groups agreed with the statement “I want to know more about coral reefs,” and while results did not differ significantly, servicemembers reported the highest agreement (81%) to this statement.

3.4.5 Questionnaire results by diving demographics

Professional divers were significantly more likely to agree with the statements “I know a lot about coral reefs” and “scuba divers can hurt corals” than recreational divers (Figure 21). Professional divers were also more likely to disagree with the statement “white corals are healthy corals” and significantly more likely to disagree with the statement “feeding fish is good for coral reefs.” Divers holding Rescue Diver or Master Diver certifications (the two highest recreational certifications) were more likely than lesser-certified divers to agree with the statements “I know a lot about coral reefs,” “divers can hurt corals,” and “I am a skilled diver.” However, Rescue and Master divers were also more likely to agree with the statements “feeding fish is good for coral reefs” and “white corals are healthy corals” than divers with lower certifications.

Agreement with the statement “I know a lot about coral reefs” increased significantly and steadily with increasing number of lifetime dives and number of dives made in the previous year. Regardless of lifetime and recent diving activity, most divers knew that fish feeding was not healthy for reefs, that white corals are not healthy corals, and that scuba divers can hurt corals. Overall most divers agreed with the statement “I want to know more about coral reefs," particularly more divers with more advanced certifications and divers who had been more active in the past year (Figure 22).

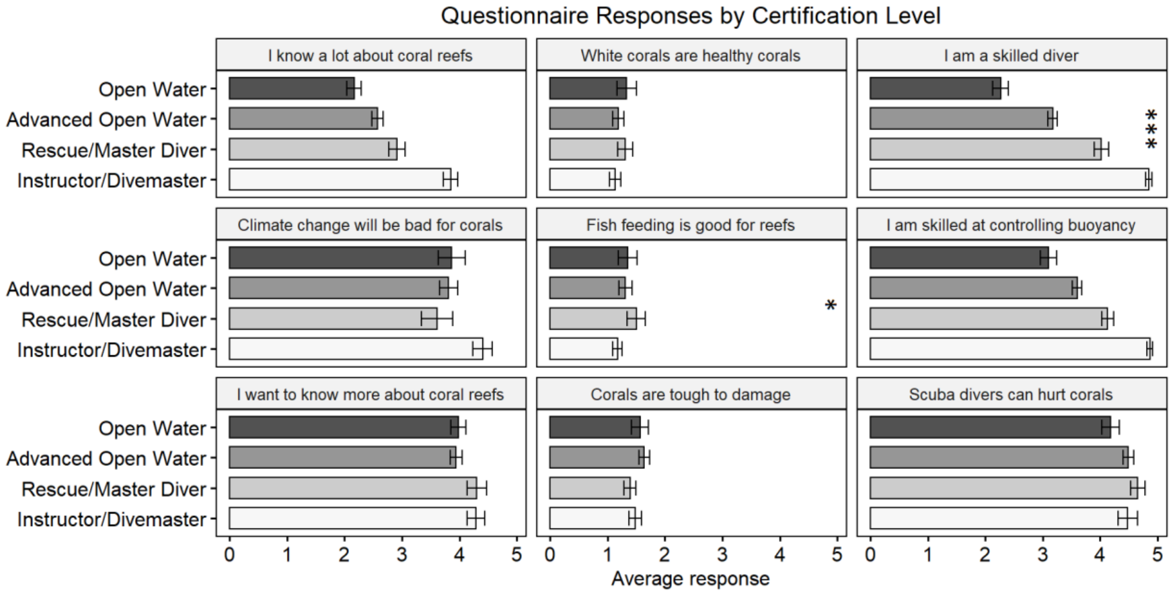

Figure 21. Average responses to questionnaire statements by diver certification level.

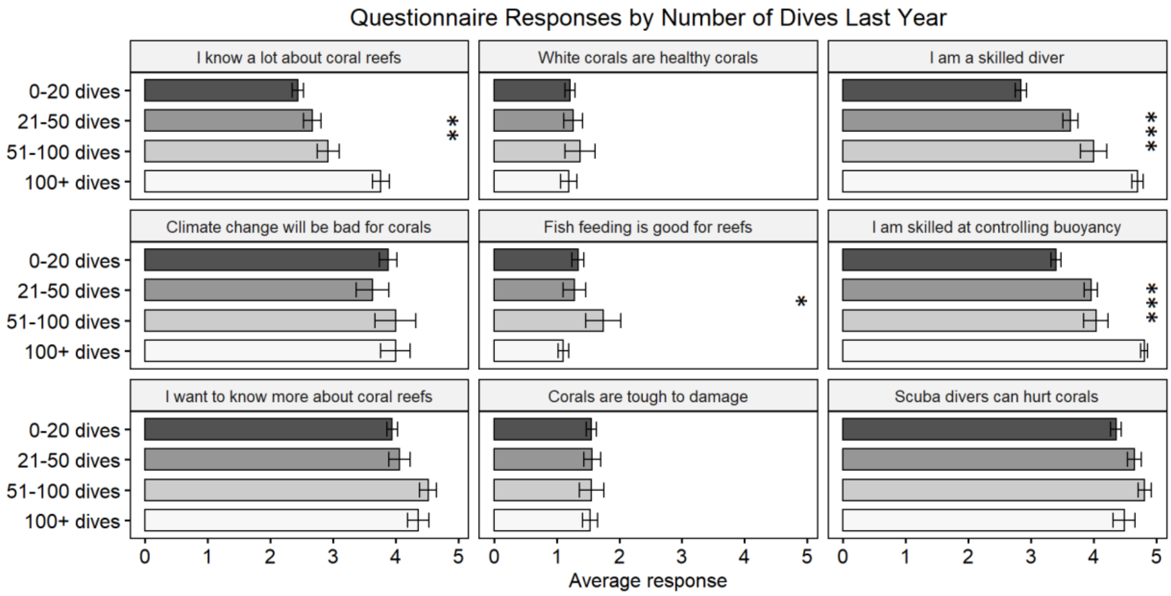

Figure 22. Average responses to questionnaire statements by number of dives completed in the last year.

3.4.6 Questionnaire results compared to contacts

Divers who agreed or disagreed with the statement "I am skilled at controlling my buoyancy" were generally making a semi-accurate self-assessment. There were significant differences in accidental contact rates between divers who agreed and those who disagreed (Figure 23). However, divers who strongly agreed with this statement had slightly higher contact rates for all contact categories than divers who agreed less strongly. Divers also made fairly accurate self-assessments for the question "How often do you accidentally kick or bump things during a dive?" (Figure 24).

Divers' answers to knowledge statements such as "White corals are healthy corals," "Scuba divers can harm corals," and "Fish feeding is good for reefs" were in no way associated with their contact rates. Some statements could not be compared to contact rates due to low numbers of respondents on either end of the scale; for example, just four divers reported that they "touch, grab, or poke corals during a dive" on every dive or most dives.

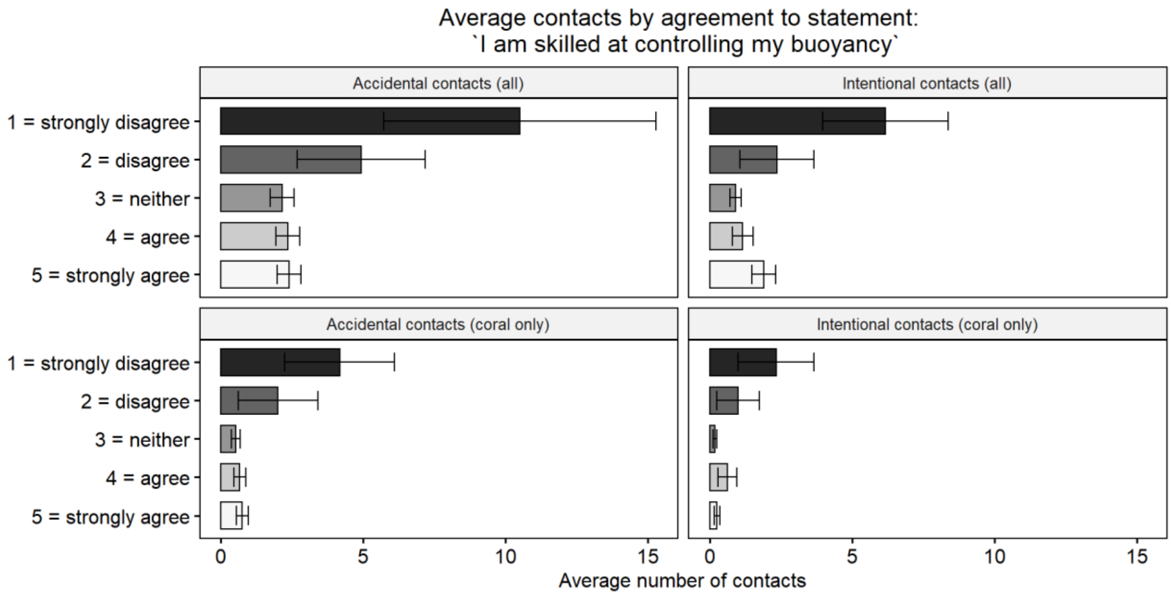

Figure 23. Average contacts by agreement to the statement "I am skilled at controlling my buoyancy."

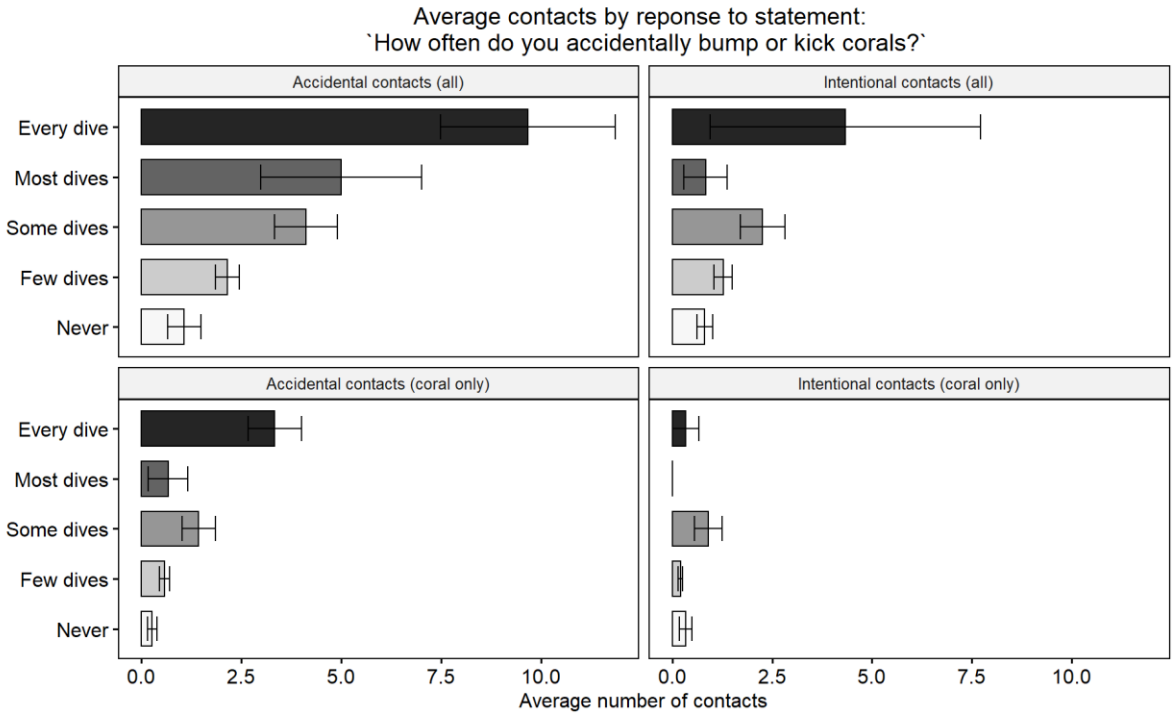

Figure 24. Average contacts by response to the statement "How often do you accidentally bump or kick corals?"

4. Discussion

4.1 Novel findings and future directions

4.1.1 Coral-safe diving reminder effectively reduces diver impacts

The coral-safe diving reminder was extremely effective in reducing diver impacts on coral reefs. Previous studies ((Barker & Roberts 2004; Camp & Fraser 2012; Giglio et al. 2018; Hammerton 2017; Medio et al. 1997; Toyoshima & Nadaoka 2015; Worachananant et al. 2008) have tested the effectiveness of variations on the coral-safe diving reminder, ranging from in-depth pre-dive briefings to mandatory video classes, but this study is novel in that it demonstrates that a large effort is not necessary for impactful results. While most divers reported that they wanted to learn more about coral reefs, comparisons of diver contact rates and questionnaire-assessed knowledge about coral reefs demonstrates that a diver's *knowledge* about reefs did not have any bearing whatsoever on their *impact* on the reef. Therefore, while education is always a worthwhile endeavor, efforts to reduce diver impacts on coral reefs through education alone are likely to fail. The coral-safe reminder tested in this study did not educate divers at all, yet it was highly effective in reducing diver contacts. This technique of simply asking divers to be mindful of their impacts costs nothing and achieves significant results without requiring much time, effort, or knowledge for the dive guide.

4.1.2 Biological impacts of divers

This study found that coral breakage was significantly more prevalent at *often dived* sites than *rarely dived* sites. Breakage was six times higher at Blue & White than Amphitheater, and 22 times higher at Finger Reef than Kilo Wharf. This breakage is likely due to a combination of scuba divers and anchor damage from dive boats. There were no significant differences in breakage between Western Shoals and Southwestern Shoals. Possible explanations for this result include an unknown source of breakage at Southwestern Shoals (perhaps turtles or boat groundings), or the site is in fact *often dived* by dive companies other than MDA.

This study found no effect of dive frequency on benthic cover or coral community patterns. Dive frequency was found to be a significant variable for algal and sponge percent cover, but these benthic categories were higher at *rarely dived* sites. This result is not unexpected; after all, high diving pressure is unlikely to lead *directly* to community changes or serious outbreaks of disease, and Guam's reefs have been heavily impacted by other stressors, such as warming waters and sedimentation. Kilo Wharf (and to a lesser extent, Finger Reef) likely suffers from water quality issues stemming from its use as a wharf for military vessels. Sedimentation within Apra Harbor can be severe; for example, visibility at Southwestern Shoals was very poor at the time of surveys. The sites within Apra Harbor have also suffered from the recent severe coral bleaching events, which killed many shallow corals, particularly *Acropora* stands that once grew on top of Western Shoals. Sites outside the harbor benefit from better water quality, but clear water may have worked against the corals by failing to protect them from irradiance. During the 2017 bleaching event, corals as deep as 40 m were observed to be bleached at Blue & White, and as deep as 30 m within Apra Harbor. The catastrophic loss of coral due to Guam's severe and successive bleaching events may be masking other impacts of scuba divers on the island's reefs.

Finally, I theorize that divers prefer to dive at sites with healthy coral and higher diversity. Dive frequency is entirely dependent on human behavior, not on natural or physical phenomena. Perhaps if the *often dived* sites were to experience a serious decline in reef health or diversity, they would become *rarely dived* sites. As climate change is likely to continue negatively impacting our coral reefs, reducing local stressors remains an important facet of their management. Despite the lack of clear evidence of diver impacts on Guam's reefs, it nevertheless remains prudent to encourage coral-safe diving behavior among residents and visitors alike.

4.1.3 Predictors of high-impact divers

This study is the first to examine the correlation between contact rates and group size, showing that divers in larger groups make significantly more individual contacts than divers in smaller groups. Furthermore, while previous studies have shown that dive guides can intervene to reduce poor diving behavior (Barker & Roberts 2004, Luna et al. 2009), this study is the first to identify a correlation between the contact rates of guides and their clients, suggesting that dive guides may influence client behavior by modelling coral-safe diving behavior. Encouraging dive guides and instructors to be more mindful of their own impacts on the reef is likely to have much broader results. Additionally, this study corroborated the findings of Harriott et al. (1997) that a small minority of divers made the overwhelming majority of reef contacts. A third of all intentional contacts were made by just 2.7% of divers, and a third of all accidental contacts were made by just 4% of divers. Therefore, dive guides may be able to focus their efforts by paying extra attention to these high-contact divers and intervening when necessary.

Divers with gloves and cameras were found to have significantly higher contact rates, which was consistent with other studies. This study found significantly different contact rates between divers with various types of cameras, which contrasts with the results of Barker & Roberts (2004), who found no difference in contact rates between "specialist and non-specialist" camera users. This study also found that divers who received a coral-safe reminder made fewer contacts than divers who did not, regardless of buoyancy control level, while Toyoshima & Nadaoka (2015) found that a similar pre-dive briefing was only effective for divers with good buoyancy control.

Divers from Asian countries exhibited significantly poorer diving behavior than divers from Guam or the United States/Hawaii in several metrics. Divers from Asia were significantly more likely than divers from Guam or the USA/HI to use a camera. Roughly 50% of divers from Asian countries using cameras, primarily of the point-and-shoot variety. Buoyancy control ratings were overall significantly poorer for divers from Asian countries than divers from Guam or the United States/Hawaii, a finding consistent with Toyoshima & Nadaoka (2015),who found that only 44% of Japanese divers could maintain neutral buoyancy. The simplest explanation for this observation is that divers who are certified in Asian countries may not be being taught to properly control their buoyancy during their certification courses; the authors recommend that "instructors should note this gap," and that more time and effort should be spent on improving divers' buoyancy control.

Overall, the results of the stepwise regression model were as I expected based on the results of the independent testing of variables. Guam residents are less likely than visitors to make accidental or intentional contacts. The use of gloves was significant for intentional contacts, but not for accidental contacts. Camera use, surprisingly, was not a significant predictor for either model, thought it did contribute to the model for intentional contacts. It is possible that camera use and region of residence may be interfering with each other, as nearly 50% of divers from Asian countries used cameras.

Surprisingly, less diving activity within the last year was associated with *lower* contact rates for both accidental and intentional contacts, and the strongest (negative) coefficient for accidental contacts was having made 0-20 dives in the previous year. I expected higher diving activity to be associated with lower contact rates in the vein of "practice makes perfect," but this does not seem to be the case. I have observed that many new, inexperienced, or out-of-practice divers tend to stay higher above the sea floor than more experienced, confident divers. More experienced divers may also be more familiar with dangerous marine flora and fauna, and therefore they may feel that they know what is "safe" (for them) to touch. Regardless of the cause, the effect is that divers who dive more often are making more contacts—which makes it all the more important to reduce the impacts of these highly active divers.

4.1.4 Questionnaire responses

This study is not the first to combine behavioral observations with socioeconomic and questionnaire data, but it does introduce new information about divers' knowledge, opinions, and beliefs.

Questionnaire data revealed several incongruencies between what divers *believe* and what they *know* or *do.* Inexperienced and newly certified divers report that they are not knowledgeable about coral reefs, but based on the results of this (admittedly basic) test of coral reef knowledge they are actually no more or less knowledgeable than very experienced divers. More advanced divers with Rescue Diver and Master Diver certifications were more likely to agree that they are knowledgeable about coral reefs, but they were also more likely to agree with incorrect statements about coral reefs (including "feeding fish is good for coral reefs" and "white corals are healthy corals") than divers with lower certifications, suggesting that their confidence in knowledge about coral reefs may be unfounded. In-water assessments of buoyancy control were generally aligned with divers' agreement with the statement "I am skilled at controlling my buoyancy." However, divers who strongly agreed with this statement may have been overestimating their abilities, as they had slightly higher contact rates for all contact categories than divers who agreed less strongly. Furthermore, divers who reported "never" accidentally kicking or bumping corals during a dive may have been overestimating their reef avoidance and buoyancy control skills, as their average contact rates were not zero.

Divers from the USA/HI and Guam residents were significantly more likely to agree with the statement “scuba divers can hurt corals” than divers from Asian countries, but divers from Asian countries were significantly more likely to cause damage to corals. This suggests that divers from Asian countries may particularly benefit from educational opportunities. Regardless of nationality, most divers reported that they wanted to learn more about coral reefs. The highest agreement to “I want to learn more about coral reefs” came from Guam’s resident military servicemembers. Offering coral reef education services to military servicemembers, particularly those newly stationed on the island, would likely be well-received. However, given that responses to coral reef knowledge questions were not associated with divers’ contact rates, education alone is unlikely to reduce the impacts of divers. The impacts of the most damaging divers are likely to be mitigated most effectively by direct instruction (such as the inclusion of a coral-safe diving reminder during dive briefings) and in-water dive guide intervention.

4.2 Recommendations

The third hypothesis of this study tested whether significant predictors of high-impact divers exist. Several relatively strong predictors of high-impact divers were revealed, allowing the null hypothesis to be rejected. Identifying these predictors may help diving professionals identify divers who may be more damaging to coral reefs than the average diver, or “high-impact” divers. The predictors tested are easily identifiable from simple observations (e.g. cameras and gloves) and allow quick and non-invasive evaluations of divers who may benefit from more attention. Ultimately, I hope that the results of this study may be used by the diving community to reduce diver impacts on coral reefs. This section is separated into three parts: (1) recommendations for diving professionals and diving operations, (2) recommendations for regulating bodies, and (3) recommendations for individual divers.

4.2.1 Diving professionals and diving operations

With climate change taking its toll on reefs worldwide, reducing local stressors is of increasing importance for reef resilience. Diving professionals who depend on coral reefs for their livelihood have a vested interest in protecting the reef. The results of this study show that significant decreases in diver-reef contact can be achieved by simply asking divers to watch their buoyancy and avoid reef contact. This simple reminder costs nothing, takes seconds to deliver, and requires almost no knowledge about coral reefs. However, the results also show that most divers want to protect coral reefs reef and learn more about them. Many divers are unfamiliar with what they are seeing, especially if they are visitors on vacation. Some divers may not even know what a coral is, let alone why they should avoid touching it. Education can go a long way in both reducing a diver's impacts *and* enhancing the diver's experience. Educational materials are readily available; I highly recommend Green Fins materials, which are free to download and available in multiple languages. This study also found that divers' reef contact rates were correlated with the contact rates of their guides and instructors. If a guide or instructor was touching corals and being careless with his/her fins, their clients were more likely to do the same. When guides and instructors displayed good buoyancy control and coral-safe diving practices, they set an example of "good" diving behavior that their customers were more likely to follow. Divers trust their guides and instructors, so leading by example and educating divers about coral reefs are the best tools in a diving professional's toolbox.

In this study I also identified predictors of "high-impact" divers. These predictors include wearing gloves, using point-and-shoot or DSLR cameras, living in Asian countries, and diving in large groups. However, it is crucial to recognize that these predictors are merely *trends*, not a mathematical formula to determine how "good" or "bad" an individual diver will be. Diving professionals are the first line of defense against reef damage from divers, and these characteristics allow dive guides and instructors to identify and pay special attention to potential "high-impact" divers. By recognizing such divers, diving professionals can take steps to reduce individual divers' impacts on the reef. For example, a dive guide may reduce the impacts of a large group of divers by recruiting another guide and splitting the large group into two smaller groups. If a diver has made a few (or no) dives in the last year, a dive guide could take a few minutes at the beginning of the dive to check the diver's buoyancy and add or remove weight as necessary.

All divers have the potential to damage the reef, and the results of this study should *not* be used to make assumptions about individual divers, to discriminate against any particular group of divers, or to deny service to certain divers. Diving professionals and diving operations *should* use the results of this study to make more informed decisions that can help their business, their customers, and the coral reefs they depend upon. For example:

- A dive shop with many tourist customers may encourage check-out dives, and/or offer a local specialty course that focuses on educating divers about local flora and fauna.
- A dive shop with a high percentage of customers from Asian countries may advertise buoyancy classes more aggressively.
- A dive shop that rents cameras may encourage divers to use GoPro cameras rather than point-and-shoot cameras, and/or offer underwater photography/videography classes that reinforce coral-safe diving practices.

As eco-tourism grows in popularity, dive shops and diving professionals may find that other reef-friendly practices benefit their business. For example, divers who see trash in the water during their dive may be motivated to buy “eco-friendly” items (such as reusable bags, water bottles, metal straws, etc.) to reduce their own waste.

Dive shops may consider adopting policies, signage, and/or reward programs that capitalize on known influences of human behavior. Psychological research has long shown that authority figures, incentives, social norms, self-image, and reputation are important influences on human behavior (Dolan et al. 2011). People are more likely to follow instructions from perceived authority figures, so simply being told by a dive guide, instructor, or boat captain to practice coral-safe diving behavior is likely to result in better-behaved divers. Informational signs have been effective in reducing other undesirable behaviors, such as shoplifting (McNees et al. 1976) and feeding animals at a zoo (Parker et al. 2018); posting simple signs, such as those provided by Green Fins, could serve to educate divers and improve underwater behavior. Altruistic behavior, which does not directly and immediately benefit the person engaging in the behavior, is strongly motivated by the need to maintain a reputation (Milinksi et al. 2002), and the knowledge that one is being watched can induce more good behavior (Koornneef et al. 2018). Several studies have shown that simply displaying images of human eyes can reduce undesirable behaviors, such as littering (Bateson et al. 2013), and increase desirable behaviors, such as honesty (Bateson, Nettle, & Roberts 2006) and charitable giving (Haley & Fessler 2005; Powell, Roberts, & Nettle 2012). Dive guides, instructors, and even other paying customers could potentially improve diver behavior by simply paying closer attention to other divers, making more eye contact underwater, and filming video of other divers.

The concept of incentives, particularly financial incentives such as cash rewards or saving money, have been instrumental in recycling and energy-saving campaigns. Dangling gauges and collisions with the reef could result in costly damages to dive gear, and reminding divers of this may be an effective deterrent against reef contact. Dive shops may also consider reward programs for positive diving behavior, such as offering a discounted dive trip to customers who complete a buoyancy improvement course, or courtesy camera rental to customers who take an underwater photography course. These programs would require the buy-in of dive shop staff and management, but as public environmental consciousness and eco-tourism continue to grow, such actions are likely be economically (as well as ecologically) beneficial to the business.

Finally, dive shops can partner with local non-governmental organizations (NGOs), such as universities and non-profits, to offer exciting and mutually beneficial opportunities for divers to assist with projects. With nearly 50% of divers reporting high interest in participating in marine-focused citizen science projects (Lucrezi et al. 2018), the diving community may represent an untapped volunteer resource for site cleanups, outreach activities, and citizen science projects. Partnerships with these organizations can result in good publicity for dive shops, novel and enriching experiences for customers, a volunteer workforce for partner organizations, and a more cohesive diving community at large.

4.2.2 Regulating bodies

Rules and regulations are difficult to pass, and often extremely difficult (or even impossible) to enforce due to a lack of public support and/or the bureaucratic nature of government. Even current environmental laws are difficult to enforce, whether due to a shortage of law enforcement personnel—as of 2019, the Guam Department of Agriculture has just six conservation officers for the entire island and surrounding waters—or lack of supporting legislation to implement laws. For example, Guam enacted a bottle deposit law in

2010, which should have imposed a 5-cent levy on all beverage containers sold on the island in an effort to increase recycling and reduce litter, but bylaws were never passed and so the law has never been implemented. However, a plastic bag ban passed by the Guam legislature in 2018, which will prevent retailers from distributing disposable plastic bags by 2021, has infused new vigor into local activist groups and raised the community's awareness of the island's environmental problems. A bill to outlaw scuba spearfishing was introduced in the Guam legislature in 2010, much to the displeasure of local fishermen; a new bill to ban scuba spearfishing was introduced in 2019, garnering much greater public support, but it could still take years to become law. Educating local communities on best practices and achieving "buy-in" from these communities is critical for garnering support for legislative efforts.

Managing coral reefs is a difficult task, requiring the managing agency to account for multiple types of users and their impacts. Reducing diver impacts by reducing the numbers of divers is generally not a feasible conservation practice, as diving tourism is an important part of the economy for many coastal communities.   Therefore, the best method of reducing cumulative diver impacts is to reduce the impacts of *individual divers* on the reef through rules, regulations, and best practices. Banning scuba spearfishing is a good start, and such laws are on the books in many places, including nearby CNMI and Palau.

Some diving communities and local governments have successfully banned the use of gloves, with proponents arguing that gloves encourage divers to touch or handle reef life. However, gloves also protect divers' hands from cold water, stings, and bites—none of which occur by reef contact. Additionally, even experienced divers can make mistakes or misjudgments. Minor coral cuts can become infected, and the briefest contact with fire coral can result in weeks of pain; these are harsh punishments for the crime of poor buoyancy. While I recommend that diving operations encourage divers to go gloveless, and that special care should be paid to divers wearing gloves, I do not recommend a wholesale ban on the use of gloves while diving.

4.2.3 Individual divers

Change in the diving community starts with individual divers. Every diver who wishes to see coral reefs in the future has a personal responsibility to do as little damage to the reefs as possible. As the popular diver saying goes, “take only photographs and leave only bubbles.” Divers should always pay attention to their position in the water column and actively avoid reef contact by practicing good buoyancy control. When diving in a new location, or when using new or rented gear, divers should take a few minutes to check their weight before beginning the dive. There are many courses available to continue diver education, including photography courses, local specialty courses, and wildlife identification courses. Skill-based diver education, such as peak performance buoyancy courses or refresher trainings, are especially important when resuming diving after periods of inactivity.

In addition to improving one’s own diving performance, interested divers may seek out opportunities to assist local organizations. Many dive shops host underwater cleanups, enlisting skilled divers to beautify dive sites and improve the habitat for marine creatures by removing tires, fishing line, ghost nets, and other trash. Citizen science projects can be an enriching and interesting opportunity, putting a diver’s experience and skill to work for the benefit of scientific research. In addition to local organizations, there are several international organizations for citizen science on coral reefs, including CoralWatch, Reef Check Australia, and Reef Environmental Education Foundation (REEF). Divers may also choose to get involved with local environmental outreach groups, promoting public awareness and supporting legislation to protect the coral reefs.

Finally, divers can support the “green economy” through thoughtful, deliberate consumption of goods and services. Choose to patronize dive shops and other businesses that offer ecologically and socially ethical products, practices, and policies. There are many resources to help divers find dive shops that are certified through Green Fins (southeast Asia) or NOAA Blue Star (United States), use fuel-efficient boats, actively minimize waste (e.g. offering reusable cups rather than disposable cups), sell eco-friendly products (e.g. coral-safe sunblock, reusable metal water bottles, etc.), and/or support local NGOs. Divers can also make donations to organizations that support ocean research and protection, such as the International Coral Reef Society or PADI’s Project Aware.

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6. Appendices

Appendix 1. Questionnaires

Appendix 1.1. Front side of questionnaire given to Guam residents.

GUAM RESIDENT DIVER SATISFACTION SURVEY

We are collecting information about diver opinions, knowledge, and safety practices. All answers are confidential, so please answer honestly. Thank you!

What is your MDA diver tag number today? _______

How old are you? ______ years

What is your gender?
- ▢ Male
- ▢ Female
- ▢ Other/I don't know

What is your marital status?
- ▢ Single
- ▢ Divorced/Separated
- ▢ Married
- ▢ Widowed
- ▢ I don't know

How many children do you have? ________

Which village do you live in? __________________

What is your highest level of education? (If you are a student, what degree are you pursuing?)
- ▢ Middle school
- ▢ High school/GED
- ▢ Technical degree
- ▢ Associate's degree
- ▢ Some college
- ▢ Bachelor's degree
- ▢ Master's degree
- ▢ Doctoral degree
- ▢ Professional degree
- ▢ Other/I don't know

What is your yearly income in US dollars?
- ▢ Less than $20,000
- ▢ $20,000 - $29,999
- ▢ $30,000 - $39,999
- ▢ $40,000 – $49,999
- ▢ $50,000 - $59,999
- ▢ $60,000 – $69,999
- ▢ $70,000 - $79,999
- ▢ $80,000 - $89,999
- ▢ $90,000 - $99,999
- ▢ $100,000 - $149,999
- ▢ $150,000 or more
- ▢ I don't know

What is your current employment status?
- ▢ Employed full-time
- ▢ Employed part-time
- ▢ Self-employed
- ▢ Unemployed
- ▢ Unable to work
- ▢ Military
- ▢ Student
- ▢ Homemaker
- ▢ Retired
- ▢ Other/I don't know

Are you an active military member or dependent?
- ▢ Active member
- ▢ Dependent
- ▢ Neither

What is your ethnicity? (Mark all that apply.)
- ▢ White
- ▢ Hispanic or Latino
- ▢ Asian
- ▢ Pacific Islander
- ▢ Black/African American
- ▢ Native American
- ▢ Other
- ▢ I don't know

How long have you stayed on Guam?
- ▢ Less than one month
- ▢ 1-3 months
- ▢ 4-6 months
- ▢ 7-12 months
- ▢ 1-2 years
- ▢ 3-5 years
- ▢ 6-10 years
- ▢ More than 10 years
- ▢ I don't know
- ▢ I don't live on Guam

About how many dives have you completed in the last year? ________

About how many dives have you completed on Guam? ________

About how many dives have you completed in your life? ________

About how long ago did you become an open water/basic certified diver? ______________

Where did you get your open water/basic certification? ____________________________

What is your current diver certification level?
- ▢ Student (not certified)
- ▢ Open Water (Basic)
- ▢ Advanced Open Water
- ▢ Rescue Diver
- ▢ Master Diver
- ▢ Divemaster
- ▢ Instructor
- ▢ Commercial Diver
- ▢ I don't know
- ▢ Other: __________

In the last year, did you take any *specialty* diver training courses? (Ex: Deep Diver, Night Diver, Enriched Air, etc.)
- ▢ Yes
- ▢ No, but I plan to take one soon
- ▢ No, and I don't plan to take any courses soon
- ▢ I don't know

Tourism makes up a large part of Guam's economy. Overall, what impact do you think tourism has on Guam? 1 = very negative impact, 5 = very positive impact

1	2	3	4	5	Don't know

Please continue on the back of this page. →

Thank you for participating in this survey. All information will be kept confidential and anonymous. The information you provide will be used to improve diving and tourism on Guam. If you have any questions about this survey, please email guamdivingsurvey@gmail.com. This survey is conducted by the University of Guam for NOAA and Guam Visitors Bureau under NOAA Grant #NA13NOS4820012.

Appendix 1.2. Back side of questionnaire given to Guam residents.

How much do you agree with the following statements? **1=Not at all, 5=Completely agree**

	1	2	3	4	5	Don't know
I know a lot about coral reefs.						
I care about protecting coral reefs.						
Overall, Guam's reefs are healthy.						
The corals on Guam's reefs are healthy.						
The fish/animals on Guam's reefs are healthy.						
Compared to other places I have dived, Guam's reefs are healthy.						
Climate change will be bad for coral reefs.						
Corals are very tough and hard to damage.						
White corals are healthy corals.						
Scuba divers can hurt corals.						
Feeding fish is good for coral reefs.						
I would like to learn more about coral reefs.						

How much do you agree with the following statements? **1=Not at all, 5=Completely agree.**

	1	2	3	4	5	Don't know
I am a skilled diver.						
I will continue my diver training.						
I am skilled at controlling my buoyancy.						
In my dive training, I was taught to avoid touching/kicking things.						
In my dive training, I learned about protecting marine life.						
Diving is important to my quality of life.						
To make sure that you are reading all the questions, please mark '2'.						
It is important to protect Guam's coral reefs.						
I would recommend Guam's reefs to other divers.						

While diving, how often do you…

	Every dive	Most dives	Some dives	Few dives	Never	Don't know
Check your gear carefully before entering the water?						
Perform a buddy check?						
Use gloves while diving?						
Use a camera while diving?						
Touch, grab, or poke animals during a dive?						
Touch, grab, or poke corals during a dive?						
Accidentally kick or bump things during a dive?						
Have trouble controlling your buoyancy?						
Stay close to your buddy?						
Perform a safety stop at the end of a dive?						

Thank you for your participation in this survey!

Appendix 1.3. Front side of questionnaire given to English-speaking visitors.

GUAM VISITOR DIVER SATISFACTION SURVEY

We are collecting information about diver opinions, knowledge, and safety practices. All answers are confidential, so please answer honestly. Thank you!

What is your MDA diver tag number today? _______

How old are you? ______ years

What is your gender?
- ☐ Male ☐ Female ☐ Other/I don't know

What is your marital status?
- ☐ Single ☐ Divorced/Separated
- ☐ Married ☐ Widowed ☐ I don't know

How many children do you have? ________

Where do you live?
- ☐ Japan ☐ Taiwan ☐ China
- ☐ Korea ☐ Russia ☐ Philippines
- ☐ FSM ☐ Hawaii ☐ Mainland USA
- ☐ Other: ____________________________

What is your highest level of education? (If you are a student, what degree are you pursuing?)
- ☐ Middle school ☐ Bachelor's degree
- ☐ High school/GED ☐ Master's degree
- ☐ Technical degree ☐ Doctoral degree
- ☐ Associate's degree ☐ Professional degree
- ☐ Some college ☐ Other/I don't know

What is your yearly income in US dollars?
- ☐ Less than $20,000 ☐ $70,000 - $79,999
- ☐ $20,000 - $29,999 ☐ $80,000 - $89,999
- ☐ $30,000 - $39,999 ☐ $90,000 - $99,999
- ☐ $40,000 – $49,999 ☐ $100,000 - $149,999
- ☐ $50,000 - $59,999 ☐ $150,000 or more
- ☐ $60,000 – $69,999 ☐ I don't know

What is your current employment status?
- ☐ Employed full-time ☐ Military
- ☐ Employed part-time ☐ Student
- ☐ Self-employed ☐ Homemaker
- ☐ Unemployed ☐ Retired
- ☐ Unable to work ☐ Other/I don't know

What is your ethnicity? (Mark all that apply.)
- ☐ White ☐ Black/African American
- ☐ Hispanic or Latino ☐ Native American
- ☐ Asian ☐ Other
- ☐ Pacific Islander ☐ I don't know

Is this your first trip to Guam?
- ☐ Yes ☐ No ☐ I don't know

How long are you staying on Guam?
- ☐ 0-3 days ☐ 1-3 months
- ☐ 4-7 days ☐ 4-6 months
- ☐ 8-13 days ☐ 7 months or longer
- ☐ 14-30 days ☐ I don't know

During this trip, about how many dives will you complete? ___________

About how many dives have you completed in the last year? ___________

About how many dives have you completed on Guam? ___________

About how many dives have you completed in your life? ___________

About how long ago did you become an open water/basic certified diver? _________________

Where did you get your open water/basic certification? ___________________________

What is your current diver certification level?
- ☐ Student (not certified) ☐ Divemaster
- ☐ Open Water (Basic) ☐ Instructor
- ☐ Advanced Open Water ☐ Commercial Diver
- ☐ Rescue Diver ☐ I don't know
- ☐ Master Diver ☐ Other: ___________

In the last year, did you take any *specialty* diver training courses? (Ex: Deep Diver, Night Diver, Enriched Air, etc.)
- ☐ Yes
- ☐ No, but I plan to take one soon
- ☐ No, and I don't plan to take any courses soon
- ☐ I don't know

Please continue on the back of this page. ➡

Thank you for participating in this survey. All information will be kept confidential and anonymous. The information you provide will be used to improve diving and tourism on Guam. If you have any questions about this survey, please email guamdivingsurvey@gmail.com. This survey is conducted by the University of Guam for NOAA and Guam Visitors Bureau under NOAA Grant #NA13NOS4820012.

Appendix 1.4. Back side of questionnaire given to English-speaking visitors.

How much do you agree with the following statements? **1=Not at all, 5=Completely agree**

	1	2	3	4	5	Don't know
I know a lot about coral reefs.						
I care about protecting coral reefs.						
Overall, Guam's reefs are healthy.						
The corals on Guam's reefs are healthy.						
The fish/animals on Guam's reefs are healthy.						
Compared to other places I have dived, Guam's reefs are healthy.						
Climate change will be bad for coral reefs.						
Corals are very tough and hard to damage.						
White corals are healthy corals.						
Scuba divers can hurt corals.						
Feeding fish is good for coral reefs.						
I would like to learn more about coral reefs.						

How much do you agree with the following statements? **1=Not at all, 5=Completely agree.**

	1	2	3	4	5	Don't know
I am a skilled diver.						
I will continue my diver training.						
I am skilled at controlling my buoyancy.						
In my dive training, I was taught to avoid touching/kicking things.						
In my dive training, I learned about protecting marine life.						
Diving is important to my quality of life.						
To make sure that you are reading all the questions, please mark '2'.						
It is important to protect Guam's coral reefs.						
I would recommend Guam's reefs to other divers.						

While diving, how often do you…

	Every dive	Most dives	Some dives	Few dives	Never	Don't know
Check your gear carefully before entering the water?						
Perform a buddy check?						
Use gloves while diving?						
Use a camera while diving?						
Touch, grab, or poke animals during a dive?						
Touch, grab, or poke corals during a dive?						
Accidentally kick or bump things during a dive?						
Have trouble controlling your buoyancy?						
Stay close to your buddy?						
Perform a safety stop at the end of a dive?						

Thank you for your participation in this survey!

Appendix 1.5. Front side of questionnaire given to Japanese-speaking visitors.

グアムに来られたダイバーの皆様満足度アンケート

アンケートにご参加いただき誠にありがとうございます。この結果を生かして、これからもグアムのダイビングの発展のため、そして水中環境の保護のために努力を重ねてまいります。

今日では、ダイバータグ番号は何ですか?（ぜひお答えください.） ________

どこにお住まいですか?
- ▢ 日本
- ▢ その他: ________________

性別? ▢ 男性 ▢ 女性

年齢?（ぜひお答えください.） ____________ オ

子供は何人いらっしゃいますか? __________

結婚歴を教えてください。
- ▢ 独身
- ▢ 離婚歴あり
- ▢ 既婚
- ▢ 未亡人
- ▢ わかりません

最終学歴?（もし学生の場合，今何年生ですか?）
- ▢ 中学校
- ▢ 大学
- ▢ 高等学校
- ▢ 修士
- ▢ 工業専門学校
- ▢ 博士
- ▢ 短期大学
- ▢ その他: ___________
- ▢ 答えたくない

あなた自身の年収は、アメリカのドルに換算するといくらぐらいですか?
- ▢ $0 – $20,000
- ▢ $70,000 – $79,999
- ▢ $20,000 – $29,999
- ▢ $80,000 – $89,999
- ▢ $30,000 – $39,999
- ▢ $90,000 – $99,999
- ▢ $40,000 –$49,999
- ▢ $100,000 – $149,999
- ▢ $50,000 – $59,999
- ▢ $150,000+
- ▢ $60,000 –$69,999
- ▢ わかりません

あなたの雇用状態を教えてください。
- ▢ 正社員/フルタイム
- ▢ ミリタリー/軍人
- ▢ パートタイム
- ▢ 学生
- ▢ 自営業
- ▢ 主婦/主夫
- ▢ 無職
- ▢ 定年退職
- ▢ 現在仕事ができない状態
- ▢ その他/わからない

人種を教えてください(あてはまるものすべてに印をつけてください。
- ▢ アジア
- ▢ 白人
- ▢ パシフィックアイランダー
- ▢ その他
- ▢ 黒人/アフリカンアメリカン
- ▢ わからない
- ▢ ヒスパニック又はラテンアメリカ

グアムへの旅行は初めてですか?
- ▢ はい
- ▢ いいえ

今回のグアムでの滞在は何日間ですか? ________

ご滞在中に何ダイブなさいますか? ___________

去年、何度くらいダイビングしましたか? _________

グアムでは、何度くらいダイビングをしたことがありますか? ________________________

今まで何ダイブ潜っていますか? ___________

どのくらい前に認定ダイバーになられましたか?
____

どこでダイバーになられましたか?
- ▢ 日本
- ▢ その他: ________________

認定レベルは何ですか?
- ▢ 認定ダイバーではない
- ▢ マスターダイバー
- ▢ オープンウォーター/ベーシック
- ▢ ダイブマスター
- ▢ インストラクター
- ▢ アドバンス
- ▢ よくわからない
- ▢ レスキュー
- ▢ その他: ________

ご滞在中に、何らかのダイバーコースを受講なさいましたか?
- ▢ はい
- ▢ いいえ、しかし近々グアムで受講の予定
- ▢ いいえ、しかし近々他の場所での受講を予定
- ▢ いいえ、近々受講する予定はありません

裏のページの質問に進んでください。 ➡

アンケートにご協力いただきありがとうございます。 アンケートの回答はすべて匿名であり、機密です。みなさまから頂いた情報は、今後のグアムのダイビングやグアム観光の改善のために使われます。もし、このアンケートにご質問がありましたら、guamdivingsurvey@gmail.com までご連絡ください。

Appendix 1.6. Back side of questionnaire given to Japanese-speaking visitors.

下記の文章にどのくらい同意しますか？ 1=いいえ、まったく同意できません，5=はい、まったくその通りです

	1	2	3	4	5	わかりません
サンゴ礁について、沢山のことを知っています。						
サンゴ礁を守ることについて関心があります。						
全体的に、グアムのサンゴ礁は健康です。						
グアムのサンゴ礁のサンゴは健康です。						
グアムのサンゴ礁でみられる魚等の海洋生物は健康です。						
グアム以外の場所でダイビングもしましたが、それらの場所に比べるとグアムのサンゴ礁は健康です。						
気候変動は、サンゴ礁に悪影響を及ぼします。						
サンゴは、とても強くて損傷しにくいです。						
白いサンゴは、健康なサンゴです。						
スキューバダイバーは、サンゴを損傷する事があります。						
魚の餌付けは、サンゴ礁にはいいことです。						
サンゴ礁について、もっと学びたいと思っています。						

下記の文章にどのくらい同意しますか？ 1=いいえ、まったく同意できません，5=はい、まったくその通りです

	1	2	3	4	5	わかりません
私は、熟練ダイバーです。						
自身のダイバートレーニングを継続していくつもりです。						
浮力をコントロールするのに熟練されてます。						
ダイビングのトレーニングを受けている時、物を触ったり蹴ったりすることを避けるように教わりました。						
ダイビングのトレーニングを受けている時、海洋生物を保護する事について学びました。						
ダイビングは、私の生活の質に大切なものです。						
すべての質問を読んで頂いているかの確認です、2に印をつけてください。						
グアムのサンゴ礁を守ることはとても大切なことです。						
グアムのサンゴ礁を、他のダイバーにも推薦します。						

ダイビングをする間、どのくらいの頻度で。。。［下記の事をしますか］

	毎回	ほとんどの時	時々	めったにしない	したことがない	わかりません
水に入る前に、ダイビングの器材を慎重に確認しますか?						
バディチェックしていますか?						
ダイビング中、グローブ(手袋)はしていますか?						
ダイビング中に、水中カメラを使用しますか?						
ダイビング中に、海洋生物に触ったり、握ったり、つついたりしたことはありますか?						
ダイビング中に、サンゴに触ったり、握ったり、つついたりしたことはありますか?						
ダイビング中に、誤ってものをけったり、ぶつかったりしたことはありますか?						
浮力をコントロールするのが困難な時がありますか?						
バディと離れずそばにいますか?						
ダイブの最後にセーフティーストップを行っていますか?						

どうもありがとうございました！

Appendix 2. Coral species and genus counts by site.

Genus	Scientific name	Amphi-theater	Blue & White	Finger Reef	Kilo Wharf	SW Shoals	Western Shoals	**Grand Total**
Acanthastrea		**11**	**9**	**1**				**21**
	Acanthastrea echinata	4	1					5
	Acanthastrea species	7	8	1				16
Acropora		**6**	**8**					**14**
	Acropora caespitose	1	1					2
	Acropora digitifera	3	4					7
	Acropora granulosa	1	3					4
	Acropora humilis	1						1
Astrea		**31**	**35**					**66**
	Astrea (Montastrea) curta	9	23					32
	Astrea (Montastrea) valenciennesi	22	12					34
Astreopora		**17**	**2**					**19**
	Astreopora listeri		1					1
	Astreopora myriopthalma	14	1					15
	Astreopora species	3						3
Cycloseris		**5**	**2**					**7**
	Cycloseris species	5	2					7
Cyphastrea		**4**	**17**		**1**			**22**
	Cyphastrea agassizi		1					1
	Cyphastrea chalcidicum		5					5
	Cyphastrea microphthalma		1		1			2
	Cyphastrea serailia	2	10					12
	Cyphastrea species	2						2
Dipsastraea (Favia)		**26**	**138**	**11**	**2**	**4**	**6**	**187**
	Dipsastraea (Favia) favus	2	74					76
	Dipsastraea (Favia) helianthoides	1	10	11	1	4	6	33
	Dipsastraea (Favia) pallida	16	26					42
	Dipsastraea (Favia) species	7	28		1			36
Echinopora			**4**					**4**
	Echinopora pacificas		4					4
Favites			**1**	**1**				**2**
	Favites flexuosa		1					1
	Favites species			1				1

Genus	Scientific name	Amphi-theater	Blue & White	Finger Reef	Kilo Wharf	SW Shoals	Western Shoals	**Grand Total**
Fungia				**1**				**1**
	Fungia species			1				1
Galaxea		**38**	**13**		**5**			**56**
	Galaxea archelia				4			4
	Galaxea fascicularis	36	13		1			50
	Galaxea longisepta	2						2
Gardineroseris			**2**					**2**
	Gardineroseris planulata		2					2
Goniastrea		**39**	**79**		**3**			**121**
	Goniastrea edwardsi	6	13		3			22
	Goniastrea retiformis	33	46					79
	Goniastrea stelligera		20					20
Goniopora		**7**						**7**
	Goniopora fruticosa	4						4
	Goniopora minor	3						3
Heliopora		**6**						**6**
	Heliopora coerulea	6						6
Herpolitha		**1**				**5**		**6**
	Herpolitha species	1				5		6
Leptastrea		**63**	**12**					**75**
	Leptastrea purpurea	62	12					74
	Leptastrea transversa	1						1
Leptoria		**7**	**71**					**78**
	Leptoria phrygia	7	71					78
Leptoseris			**2**			**1**	**1**	**4**
	Leptoseris incrustans					1	1	2
	Leptoseris species		2					2
Lobophyllia			**1**					**1**
	Lobophyllia hemprichii		1					1
Merulina			**1**					**1**
	Merulina ampliata		1					1
Montipora		**3**						**3**
	Montipora verrucosa	3						3

Genus	Scientific name	Amphi-theater	Blue & White	Finger Reef	Kilo Wharf	SW Shoals	Western Shoals	Grand Total
Pachyseris					**1**			**1**
	Pachyseris gemmifera				1			1
Pavona		**9**	**18**	**2**	**4**	**6**	**1**	**40**
	Pavona cactus					6		6
	Pavona chriquiensis		2					2
	Pavona varians	9	16	2	4		1	32
Platygyra		**16**	**44**					**60**
	Platygyra daedalea	2	5					7
	Platygyra pini	14	39					53
Plesiastrea		**1**	**2**					**3**
	Plesiastrea versipora	1	2					3
Pocillopora		**2**	**2**			**37**	**20**	**61**
	Pocillopora damicornis	2	2			37	18	59
	Pocillopora species						2	2
Porites		**562**	**413**	**602**	**287**	**739**	**650**	**3253**
	Porites australiensis		2					2
	Porites c.f. densa	4						4
	Porites cylindrica			2		10		12
	Porites deformis	27						27
	Porites mammalata		32					32
	Porites massive	472	158		3		5	638
	Porites monticulosa						9	9
	Porites rus	56	221	600	284	729	636	2526
	Porites species	2						2
	Porites vaughani	1						1
Psammocora		**13**	**32**					**45**
	Psammocora nierstraz	3	28					31
	Psammocora profundacella	8	4					12
	Psammocora species	1						1
	Psammocora stellata	1						1
Sinularia				**2**			**1**	**3**
	Sinularia sp.			2			1	3
Stylocoeniella			**12**		**3**	**1**	**3**	**19**
	Stylocoeniella armata		12		3	1	3	19
Unidentified corals		**4**	**1**				**6**	**11**
Grand Total		**871**	**921**	**620**	**306**	**793**	**688**	**4199**

Appendix 3. Coral species and genus counts by size class.

Genus / Scientific Name Size Class	1	2	3	4	5	6	Grand Total
Acanthastrea	**14**	**7**					**21**
Acanthastrea echinata	4	1					5
Acanthastrea species	10	6					16
Acropora	**13**	**1**					**14**
Acropora caespitose	2						2
Acropora digitifera	7						7
Acropora granulosa	3	1					4
Acropora humilis	1						1
Astrea	**41**	**20**	**4**			**1**	**66**
Astrea (Montastrea) curta	27	5					32
Astrea (Montastrea) valenciennesi	14	15	4			1	34
Astreopora	**13**	**6**					**19**
Astreopora listeri	1						1
Astreopora myriopthalma	11	4					15
Astreopora species	1	2					3
Cycloseris	**5**	**2**					**7**
Cycloseris species	5	2					7
Cyphastrea	**12**	**10**					**22**
Cyphastrea agassizi	1						1
Cyphastrea chalcidicum	2	3					5
Cyphastrea microphthalma		2					2
Cyphastrea serailia	7	5					12
Cyphastrea species	2						2
Dipsastraea (Favia)	**102**	**74**	**7**	**2**	**2**		**187**
Dipsastraea (Favia) favus	41	35					76
Dipsastraea (Favia) helianthoides	20	9	2		2		33
Dipsastraea (Favia) pallida	22	20					42
Dipsastraea (Favia) species	19	10	5	2			36
Echinopora	**3**	**1**					**4**
Echinopora pacificas	3	1					4
Favites	**1**	**1**					**2**
Favites flexuosa		1					1
Favites species	1						1
Fungia		**1**					**1**
Fungia species		1					1

Genus / Scientific Name	Size Class	1	2	3	4	5	6	Grand Total
Galaxea		**53**	**3**					**56**
Galaxea archelia		4						4
Galaxea fascicularis		47	3					50
Galaxea longisepta		2						2
Gardineroseris		**1**	**1**					**2**
Gardineroseris planulata		1	1					2
Goniastrea		**64**	**54**	**3**				**121**
Goniastrea edwardsi		9	12	1				22
Goniastrea retiformis		50	27	2				79
Goniastrea stelligera		5	15					20
Goniopora		**6**	**1**					**7**
Goniopora fruticosa		3	1					4
Goniopora minor		3						3
Heliopora		**1**	**5**					**6**
Heliopora coerulea		1	5					6
Herpolitha			**4**	**2**				**6**
Herpolitha species			4	2				6
Leptastrea		**72**	**3**					**75**
Leptastrea purpurea		72	2					74
Leptastrea transversa			1					1
Leptoria		**15**	**35**	**21**	**7**			**78**
Leptoria phrygia		15	35	21	7			78
Leptoseris		**2**	**2**					**4**
Leptoseris incrustans			2					2
Leptoseris species		2						2
Lobophyllia			**1**					**1**
Lobophyllia hemprichii			1					1
Merulina			**1**					**1**
Merulina ampliata			1					1
Montipora		**2**	**1**					**3**
Montipora verrucosa		2	1					3
Pachyseris			**1**					**1**
Pachyseris gemmifera			1					1

Genus / Scientific Name	Size Class	1	2	3	4	5	6	Grand Total
Pavona		**29**	**7**	**2**	**2**			**40**
Pavona cactus		3		2	1			6
Pavona chriquiensis		1	1					2
Pavona varians		25	6		1			32
Platygyra		**26**	**21**	**10**	**3**			**60**
Platygyra daedalea		3	2	2				7
Platygyra pini		23	19	8	3			53
Plesiastrea		**2**	**1**					**3**
Plesiastrea versipora		2	1					3
Pocillopora		**39**	**22**					**61**
Pocillopora damicornis		37	22					59
Pocillopora species		2						2
Porites		**1444**	**959**	**502**	**204**	**115**	**29**	**3253**
Porites australiensis			1	1				2
Porites c.f. densa			4					4
Porites cylindrica		8	3	1				12
Porites deformis		10	13	3	1			27
Porites mammalata		32						32
Porites massive		168	273	159	36	1	1	638
Porites monticulosa		4	2	3				9
Porites rus		1219	663	335	167	114	28	2526
Porites species		2						2
Porites vaughani		1						1
Psammocora		**26**	**16**	**3**				**45**
Psammocora nierstraz		12	16	3				31
Psammocora profundacella		12						12
Psammocora species		1						1
Psammocora stellata		1						1
Sinularia		**3**						**3**
Sinularia sp.		3						3
Stylocoeniella		**18**	**1**					**19**
Stylocoeniella armata		18	1					19
Unidentified coral		**8**	**2**	**1**				**11**
Unidentified coral		8	2	1				11
Grand Total		**2015**	**1264**	**555**	**218**	**117**	**30**	**4199**

Appendix 4. Descriptive tables of benthic cover by substrate type

Table 15. Descriptive table of live hard coral cover.

Site Pair ID	Harbor Location	Site Name	Dive Frequency	Depth	n	Mean % Cover	St. Dev.	Max	Min
H1	Inner	SW Shoals	Rarely	Deep	4	0.446	0.108	0.548	0.299
H1	Inner	SW Shoals	Rarely	Shallow	4	0.871	0.039	0.912	0.834
H1	Inner	Western Shoals	Often	Deep	4	0.380	0.257	0.609	0.150
H1	Inner	Western Shoals	Often	Shallow	4	0.751	0.090	0.830	0.659
H2	Inner	Finger Reef	Often	Deep	4	0.615	0.083	0.726	0.527
H2	Inner	Finger Reef	Often	Shallow	4	0.821	0.054	0.861	0.743
H2	Inner	Kilo Wharf	Rarely	Deep	4	0.429	0.138	0.564	0.269
H2	Inner	Kilo Wharf	Rarely	Shallow	4	0.772	0.053	0.822	0.711
O1	Outer	Amphitheater	Rarely	Deep	4	0.374	0.174	0.632	0.260
O1	Outer	Amphitheater	Rarely	Shallow	4	0.335	0.107	0.440	0.207
O1	Outer	Blue & White	Often	Deep	4	0.276	0.146	0.484	0.172
O1	Outer	Blue & White	Often	Shallow	4	0.498	0.139	0.661	0.339

Table 16. Descriptive table of algal cover.

Site Pair ID	Harbor Location	Site Name	Dive Frequency	Depth	n	Mean % Cover	St. Dev.	Max	Min
H1	Inner	SW Shoals	Rarely	Deep	4	0.146	0.079	0.239	0.045
H1	Inner	SW Shoals	Rarely	Shallow	4	0.042	0.021	0.072	0.029
H1	Inner	Western Shoals	Often	Deep	4	0.137	0.198	0.432	0.017
H1	Inner	Western Shoals	Often	Shallow	4	0.056	0.064	0.144	0.003
						0.239	0.088	0.340	0.140
H2	Inner	Finger Reef	Often	Deep	4	0.064	0.046	0.133	0.035
H2	Inner	Finger Reef	Often	Shallow	4	0.302	0.167	0.508	0.117
H2	Inner	Kilo Wharf	Rarely	Deep	4	0.117	0.052	0.172	0.057
H2	Inner	Kilo Wharf	Rarely	Shallow	4	0.024	0.013	0.032	0.005
						0.039	0.016	0.054	0.021
O1	Outer	Amphitheater	Rarely	Deep	4	0.010	0.017	0.035	0.000
O1	Outer	Amphitheater	Rarely	Shallow	4	0.007	0.012	0.025	0.000
O1	Outer	Blue & White	Often	Deep	4	0.146	0.079	0.239	0.045
O1	Outer	Blue & White	Often	Shallow	4	0.042	0.021	0.072	0.029

Table 17. Descriptive table of sponge cover.

Site Pair ID	Harbor Location	Site Name	Dive Frequency	Depth	n	Mean % Cover	St. Dev.	Max	Min
H1	Inner	SW Shoals	Rarely	Deep	4	0.100	0.090	0.236	0.051
H1	Inner	SW Shoals	Rarely	Shallow	4	0.049	0.020	0.063	0.019
H1	Inner	Western Shoals	Often	Deep	4	0.014	0.008	0.023	0.005
H1	Inner	Western Shoals	Often	Shallow	4	0.012	0.009	0.019	0.000
						0.002	0.005	0.009	0.000
H2	Inner	Finger Reef	Often	Deep	4	0.026	0.031	0.069	0.003
H2	Inner	Finger Reef	Often	Shallow	4	0.014	0.014	0.034	0.005
H2	Inner	Kilo Wharf	Rarely	Deep	4	0.019	0.020	0.045	0.000
H2	Inner	Kilo Wharf	Rarely	Shallow	4	0.000	0.000	0.000	0.000
						0.000	0.000	0.000	0.000
O1	Outer	Amphitheater	Rarely	Deep	4	0.000	0.000	0.000	0.000
O1	Outer	Amphitheater	Rarely	Shallow	4	0.000	0.000	0.000	0.000
O1	Outer	Blue & White	Often	Deep	4	0.100	0.090	0.236	0.051
O1	Outer	Blue & White	Often	Shallow	4	0.049	0.020	0.063	0.019

Appendix 5. Diversity table

Table 18. Diversity indices averaged by site and depth.

Site	Depth	Shannon (H)	Simpson	Richness (S)	Evenness (J)
Amphitheater	Deep	1.51136	0.598079	13.33333	0.589274
Amphitheater	Shallow	1.333957	0.536613	12.75	0.52529
Blue & White	Deep	1.824835	0.759332	12.33333	0.726889
Blue & White	Shallow	1.710326	0.677136	14.66667	0.634537
Finger Reef	Deep	0.124052	0.057783	2	NaN
Finger Reef	Shallow	0.083993	0.038414	1.5	NaN
Kilo Wharf	Deep	0.474182	0.209011	4	NaN
Kilo Wharf	Shallow	0	0	1	NaN
Southwestern Shoals	Deep	0.22447	0.101168	3	0.189043
Southwestern Shoals	Shallow	0.337476	0.169095	2.5	0.385199
Western Shoals	Deep	0.371917	0.175683	3.5	0.324735
Western Shoals	Shallow	0.124858	0.05124	2.25	0.162264

Appendix 6. Contact rates tables

Table 19. Average contact rates by coral-safe reminder treatment.

	Accidental contacts***	Intentional contacts***	Accidental coral contacts	Intentional coral contacts
No coral reminder (n = 315)	47.8 ± 4.2	22.4 ± 2.3	19.5 ± 3.1	7.3 ± 1.3
Coral reminder (n = 135)	12.9 ± 2.4	6.4 ± 1.3	8.5 ± 1.7	2.6 ± 0.7

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 20. Average contact rates by region of residence.

	Accidental contacts***	Intentional contacts**	Accidental coral contacts***	Intentional coral contacts**
Asia (n = 124)	55.6 ± 7.9	25.0 ± 3.9	27.7 ± 6.1	11.1 ± 2.7
Guam (n = 184)	21.8 ± 3.2	15.7 ± 2.8	8.7 ± 2.5	4.4 ± 1.4
USA/HI (n = 44)	34.1 ± 8.9	8.7 ± 2.7	13.0 ± 5.5	1.6 ± 1.0

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 21. Average contact rates by training with the last year.

	Accidental contacts*	Intentional contacts	Accidental coral contacts*	Intentional coral contacts
Training (n = 90)	19.0 ± 3.2	15.9 ± 2.9	6.0 ± 1.3	3.3 ± 0.9
No training (n = 160)	45.8 ± 6.7	22.5 ± 3.6	24.7 ± 5.5	9.3 ± 2.3

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 22. Average contact rates by camera type.

Camera Type	Accidental contacts	Intentional contacts**	Accidental coral contacts	Intentional coral contacts***
None (n = 264)	29.2 ± 3.6	15.1 ± 2.2	12.8 ± 2.7	4.8 ± 1.3
GoPro (n = 74)	27.2 ± 5	7.7 ± 1.6	11.7 ± 3	1.6 ± 0.7
Point-and-shoot (n = 68)	56.5 ± 10.2	30.0 ± 6.3	26.1 ± 6.1	16.9 ± 4.4
DSLR (n = 9)	28.0 ± 13	49.3 ± 16.3	18.7 ± 10.6	38.7 ± 16.6

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 23. Average contact rates by glove use.

	Accidental contacts**	Intentional contacts**	Accidental coral contacts	Intentional coral contacts**
No gloves (n = 339)	30.6 ± 3.1	15.4 ± 1.8	14.4 ± 2.4	5.8 ± 1.1
Gloves (n = 99)	51.0 ± 7.5	27.6 ± 5.1	21.0 ± 4.5	12.2 ± 3.4

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 24. Average contact rates by buoyancy control level.

Buoyancy Control Level	Accidental contacts***	Intentional contacts	Accidental coral contacts**	Intentional coral contacts
Good (n = 328)	24.1 ± 2.5	16.2 ± 2.1	9.8 ± 1.4	6.6 ± 1.3
Fair (n = 86)	65.9 ± 9.1	14.2 ± 3.3	33.8 ± 7.0	6.3 ± 2.7
Poor (n = 18)	105.3 ± 34.7	17.0 ± 5.1	64.3 ± 34.2	4.0 ± 2.2

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Table 25. Average contact rates by group size.

Group Size	Accidental contacts*	Intentional contacts*	Accidental contacts (coral only)**	Intentional contacts (coral only)**
2-4 divers (n = 275)	29.2 ± 3.2	14.7 ± 2	10.8 ± 1.7	4.2 ± 1
5-8 divers (n = 119)	54.8 ± 7.7	26.8 ± 4.7	31.4 ± 6.5	15.2 ± 3.4

(Stars denote significance: * = p < 0.05, ** = p < 0.001, and *** = p < 0.0001.)

Appendix 7. Demographic Information

Gender

Male	59.9%
Female	40.1%

Age

Under 18	1.9%
18-24	7.2%
25-29	14.5%
30-34	17.8%
35-39	13.7%
40-49	19.8%
50-59	20.5%
60-69	4.6%

Marital status

Single	39.70%
Married	55.40%
Divorced/Separated	4.90%

Military status

Civilian	43.5%
Active Duty Military	39.60%
Dependent	16.90%

Country of residence

Guam	48.00%
Mainland USA	11.20%
Hawaii	0.70%
Japan	26.80%
Korea	4.40%
China	3.70%
Hong Kong	2.80%
Taiwan	0.20%
Other	2.10%

Education

High school/GED	14.00%
Associate/Technical degree	9.40%
Some college	9.60%
Bachelor’s degree	41.10%
Master’s degree	18.00%
Doctoral/Professional degree	7.90%

Employment status

Employed full-time	45.2%
Employed part-time	3.9%
Self-employed	13.9%
Military	24.4%
Homemaker	3.6%
Student	3.9%
Retired	2.7%
Unemployed	1.8%
Unable to work	0.3%
Other/I don’t know	0.3%

Income

Less than $20,000	6.50%
$20,000 - $29,999	6.20%
$30,000 - $39,999	9.30%
$40,000 - $49,999	7.90%
$50,000 - $59,999	7.90%
$60,000 - $69,999	12%
$70,000 - $79,999	8.90%
$80,000 - $89,999	6.20%
$90,000 - $99,999	3.40%
$100,000 - $149,999	17.50%
$150,000 or more	14.10%

Visitor trip length

0-3 days	7.90%
4-7 days	61.20%
8-13 days	15.90%
14-30 days	5.60%
1-3 months	4.20%
4-6 months	2.80%
7 months or longer	2.30%

Appendix 8. Diving demographics

Certification level	
Open Water (Basic)	25.60%
Advanced Open Water	39.10%
Rescue Diver	10.70%
Master Diver	5.50%
Divemaster	6.50%
Instructor	12.70%
Dives completed in previous year	
0 dives	5.60%
1-5 dives	17.50%
6-10 dives	17.80%
11-20 dives	15.70%
21-50 dives	15.70%
51-75 dives	4.50%
76-100 dives	4.70%
More than 100 dives	18.40%
Dives completed in lifetime	
1-5 dives	5.70%
6-10 dives	10.10%
11-15 dives	9.40%
16-20 dives	4.70%
21-30 dives	5.70%
31-50 dives	8.60%
51-75 dives	7.90%
76-100 dives	5.90%
101-200 dives	15%
201-1000 dives	17.70%
1000+ dives	9.40%
Time since open-water certification	
Within the last week	5.70%
Within the last month	4%
Within the last 6 months	9.70%
Within the last year	6%
1-2 years ago	14.40%
3-5 years ago	13.60%
6-10 years ago	17.10%
11-20 years ago	12.20%
20+ years ago	17.40%

Appendix 9. Institutional Review Board approval

UNIVERSITY OF GUAM
1952-2012

Committee on Human Research Subjects (CHRS)
Institutional Review Board

Dr. Unaisi W. Nabobo-Baba
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Date: August 30th, 2015

To: Ashton Williams

From: Dr. Unaisi Nabobo-Baba (Chair, UOG Committee on Human Research S ubjects

RE: Approval of (**CHRS#15-61): Can pre-dive briefings reduce diver-induced damages to coral**

Dear Ashton Williams

Your completed application for CHRS review with the accompanying documents has been received and reviewed. Your proposed study: (**CHRS#15-61): Can pre-dive briefings reduce diver-induced damages to coral**

is **exempt** from the requirements for review under the federal guidelines CFR 45, Part 46.

As a result approval of this project has been granted as of August 30th, 2015. Therefore you may collect data. Should the project period extend beyond a 1 year period (12 months from approval), please be sure to submit an appropriate request for an extension of study.

Should any changes in procedures be made, UOG's CHRS must be informed and a review of the procedures and changes must be completed before they are implemented.

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