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Research article

Time to stop mucking around? Impacts of underwater photography on cryptobenthic fauna found in soft sediment habitats

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ABSTRACT

Scuba diving tourism is a sustainable source of income for many coastal communities, but can have negative environmental impacts if not managed effectively. Diving on soft sediment habitats, typically referred to as ‘muck diving’, is a growing multi-million dollar industry with a strong focus on photographing cryptobenthic fauna. We assessed how the environmental impacts of scuba divers are affected by the activity they are engaged in while diving and the habitat they dive in. To do this, we observed 66 divers on coral reefs and soft sediment habitats in Indonesia and the Philippines. We found diver activity, specifically interacting with and photographing fauna, causes greater environmental disturbances than effects caused by certification level, gender, dive experience or age. Divers touched the substrate more often while diving on soft sediment habitats than on coral reefs, but this did not result in greater environmental damage on soft sediment sites. Divers had a higher impact on the substrate and touch animals more frequently when observing or photographing cryptobenthic fauna. When using dSLR-cameras, divers spent up to five times longer interacting with fauna. With the unknown, long-term impacts on cryptobenthic fauna or soft sediment habitats, and the increasing popularity of underwater photography, we argue for the introduction of a muck diving code of conduct.

1. Introduction

The cumulative impacts of fishing, pollution and climate change are causing a decline in the health of oceans habitats across the world (Burke et al., 2011; Alongi, 2015; Halpern et al., 2015; Wernberg et al., 2016). The effects of this decline are felt most strongly in countries that depend on ocean resources for people's livelihoods (Burke et al., 2011; Lavides et al., 2016). Developing countries in particular often have a high proportion of their population reliant on marine ecosystems through subsistence fishing, building materials, or food production (Barange et al., 2014; Lavides et al., 2016). Livelihoods created by marine tourism are often suggested as sustainable alternatives to extractive activities such as fishing (Job and Paesler, 2013).

Scuba diving is one of the world's fastest growing recreational sports (Musa and Dimmock, 2012), estimated to be worth over a billion dollar globally (Garrod, 2008). Scuba diving tourism creates thousands of jobs in developing countries which can be sustainable if managed correctly (Vianna et al., 2012; Job and Paesler, 2013; De Brauwer et al., 2017). However, scuba diving can also have considerable impacts on fragile fauna living on coral reefs (Hasler and Ott, 2008). Poorly managed dive tourism can alter fish behaviour (Shackley, 1998), increase pollution, and cause habitat degradation (Wong, 1998). Careless diver behaviour has been repeatedly shown to cause damage to corals (e.g. Rouphael and Inglis, 2001; Hasler and Ott, 2008), with heavily dived sites having a higher incidence of coral disease (Lamb et al., 2014). Divers tend to cause the greatest amount of damage at the start of a dive while they are still adjusting buoyancy (Rouphael and Inglis, 2001; Roche et al., 2016). Inexperienced divers with poorly developed technical skills are more likely to cause damage than more experienced divers (Thapa et al., 2006; Chung et al., 2013), while goal orientated diving behaviour such as photography has a higher impact than general dive activities (Uyarra and Côté, 2007; Chung et al., 2013).

Divers not only have a potential impact on a reef's structure, they also affect coral-associated fauna. While the effects of divers

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on habitat forming structures, such as corals have been comprehensively described, less is known about how scuba diving impacts mobile animals (Trave et al., 2017). Studies on megafauna such as sharks and rays have shown that diver interactions can reduce mobility and change feeding behaviour (Shackley, 1998; Clua et al., 2010). For small cryptic fishes, interactions with divers can lead to short-term behavioural changes (Harasti and Gladstone, 2013). The presence of divers can also disturb fish spawning aggregations (Heyman et al., 2010), and boat can noise disrupt fish larvae from settling onto coral reefs (Holles et al., 2013).

The literature on diver impacts on coral reefs is extensive (Rouphael and Inglis, 2001; Hasler and Ott, 2008; Au et al., 2014), but scuba diving is not limited to coral reefs. There has been little research into the impacts of divers in other habitats (e.g. Sala et al., 1996; Bravo et al., 2015). Divers are more likely to touch benthic organisms on artificial reefs than on coral reefs, leading to more damage (Giglio et al., 2016). High numbers of snorkelers can alter the morphology and growth of seagrass (Herrera-Silveira et al., 2010). Understanding these impacts is imperative because ecosystems such as soft sediment habitats or seagrass beds are often more productive than coral reefs and have similarly high economic values (Boucher et al., 1998; Costanza et al., 2014). Considering the millions of active divers in areas without coral and the rise of alternative dive destinations away from coral reefs (Lew, 2013), it is important to assess the impacts divers might have on these non-reef environments.

One such alternative type of diving is diving on soft sediment, typically referred to as 'muck diving'. Muck diving is increasingly popular and is valued at over USD$ 152 million per year in Indonesia and the Philippines (De Brauwer et al., 2017). It is estimated that more than 100,000 divers annually visit muck diving destinations in Southeast Asia. Typical muck dive sites have no or very sparse coral cover, instead consisting mainly of sand with sporadic sponge or algal growth. This specialised diving activity focuses on observing or photographing cryptobenthic species such as frogfishes or seahorses that are rarely encountered on coral reefs. The search for rare species makes this a highly goal-driven type of diving that attracts very experienced divers and large numbers of photographers (De Brauwer et al., 2017). Photographers occasionally use 'muck sticks' to coax animals into better position for photographs, which could lead to stress in animals (Roche et al., 2016). Goal driven diving activities, such as photography, that focus on cryptic fish causes more damage on coral reefs than diving with a non-cryptic focus (Uyarra and Côté, 2007), but it remains unclear if this is the same on soft sediment habitats.

Multiple factors can alter the behaviour of divers. The strong focus on observing cryptic species in muck diving raises the question of whether a diver's behaviour might change depending on the species that is observed. Encountering and photographing animals that are considered rare could lead to decreased compliance to environmental ethics (Uyarra and Côté, 2007). The best predictors for high impact diver behaviours have yet to be fully identified.

The aim of this study is to better understand the varying impacts of diver activities in different marine environments. We do this by assessing diver behaviour in both coral reef and soft sediment (muck) habitats, the specific goals of this study are to investigate if the impacts of diver behaviour change with:

1) the activity divers are engaged in,
2) the habitat divers are found,
3) the type of camera divers are using, and
4) diver certification level, age, and experience.

We also investigate:

5) how these factors affect the duration of divers interaction with cryptobenthic fauna.

2. Methods

2.1. Location

Diver surveys were conducted between March and May 2016 on 33 sites in three locations in Indonesia (Bali, Nusa Tenggara, Lembeh Strait) and one location in Philippines (Dauin). All locations are important dive destinations with coral reef and soft sediment dive sites, which are visited by divers interested in photography (De Brauwer et al., 2017). Sites were determined independently by the dive centres without the influence of the researchers. At all four locations, divers were observed on both coral reefs (coral, N = 15 sites) and soft sediment slopes (muck, N = 18 sites). Maximum depth for all dives was 30 m, topography of coral reef sites were comparable to each other, and soft sediment sites all had a similar, sloping topography. Ten visited dive sites were protected areas where no fishing was allowed, but the majority of sites (N = 23 sites) had no form of official protection.

2.2. Diver observations

Divers were observed during dives conducted with eight different dive centres that offered muck and coral reef dives. All dive centres gave pre-dive briefings which outlined dive profile and included advice not to touch fragile marine life. The divers were observed ad hoc, starting with the diver closest to the observer and rotating between divers until all divers in the group had been observed. When limited divers were available over the course of a day, the same divers were observed during multiple dives, which could be on different substrates (N = 30 divers). Two types of observations were conducted: "standard observations" and "interaction observations", adapted from the methods used by Uyarra and Côté (2007). "Standard observations" were used to gauge normal diver behaviour, whereas "interaction observations" investigated divers' behaviour close to cryptobenthic fauna. Standard and interaction observations occurred during the same dives. An initial five minute standard observation was conducted for each diver after they had established neutral buoyancy and were swimming normally while watching, or photographing non-cryptic reef fauna. Divers generally cause more damage in the first phase of a dive (Camp and Fraser, 2012), but this study aimed to investigate behaviour during the body of the dive, rather than the initial buoyancy adjusting phase. Interaction observations where conducted when divers observed, photographed or otherwise interacted with cryptobenthic fauna. Interaction observations ran as long as the diver interacted with cryptobenthic fauna. If divers encountered cryptobenthic fauna during standard observations, observations were paused until the diver resumed normal swimming. Both recreational divers (tourists) and professional divers (dive guides) were observed during this study. No observations were made when conditions were suboptimal, such as strong currents or very low visibility (<4 m). Observations were conducted from a distance of 2 m − 4 m from divers, which was sufficient to observe divers and cryptobenthic fauna. To ensure normal diver behaviour divers were made aware that a marine scientist had joined the dive, but were unaware that the marine scientist would be observing their behaviours.

During interaction observations, we recorded duration of interactions, number of times a diver made contact with the substrate or an animal, and whether contacts were intentional or not (Uyarra and Côté, 2007). We further noted which part of the body or equipment touched the substrate or animal and the type of activity the diver was doing during the interaction (observe, photograph, show animal to other diver). If the substrate was damaged by the diver ("breakage, abrasions, detachment of tissue" - (Rouphael and Inglis, 2001), this was also recorded. All observations were recorded by one observer (MDB).

After the dive, divers were informed of the purpose of the research and asked to give their permission for researchers to use the data. All divers consented. During this conversation, divers were asked for information about their certification level, total number of dives, gender, and age. Finally, for divers using a camera, the type of camera was recorded (Non specialist point-and-shoot (Compact) or digital Single Lens Reflex (dSLR)). Since it is common practice in muck dive tourism for divers go out in small groups (<4 divers), the number of divers that could be observed daily per dive centre was limited.

2.3. Cryptobenthic fauna

As the cryptobenthic species of interest to divers are often rare we chose to record interactions with any species considered to be cryptobenthic. For this study cryptobenthic fauna were defined as; mobile fish or invertebrate species that "closely resemble a part of a substratum, a plant, or a sedentary animal such as a sponge or soft coral" (Randall, 2005), or species that are "behaviourally cryptic and are <50 mm" (adapted from Depczynski and Bellwood, 2003). Species were later classified per meaningful taxonomic unit, either as a family or order.

2.4. Analysis

To compare if divers behaved differently between standard observations and interactions, observed interaction data were totalled per diver and then standardised. Frequencies of divers touching the substrate or animals were standardised to frequency per 10 min. Differences between standard and interaction observations were tested using paired Wilcoxon (W) tests as data did not meet assumptions of normality. Data met assumptions for the paired Wilcoxon test.

For standard observations, the effects of habitat, camera use, and diver demographics (age, gender, diver level, total number of logged dives) on contact frequency were tested using Kruskal-Wallis (KW) tests, followed by pairwise rank sum Wilcoxon tests to investigate significant effects. To compare the effect of different variables on contact frequency during interactions with cryptobenthic fauna, touch frequencies were totalled per variable for each diver. Frequencies were then standardised to 10 min. Kruskal-Wallis tests were then used to test the effects of activity (observe, photograph, show animal), habitat (coral reef, soft sediment substrate), camera (No, Compact, dSLR), and diver demographics (age, gender, certification level, total number of logged dives) on contact frequency, damage events, and touching animals. Significant effects were further investigated using pairwise Wilcoxon rank sum tests. Sample sizes were too small to test the effects of diver demographics between different habitats and photographer categories.

The duration of diver interactions with animals was summed per family for each diver and then log10-transformed to meet assumptions of normality. A repeated measures ANOVA-design with diver as a random factor was used to test the effects of activity, habitat, camera, and family on the duration of animal-interactions. Observations of dive guides interacting with cryptobenthic fauna were omitted from these interaction duration analyses, as dive guides interactions depend on the time divers spend interacting with animals.

There was a strong correlation between the total number of instances a diver touched the substrate with the number of instances a diver intentionally touched the substrate ($r = 0.83$, $p < 0.001$). Therefore, the observations of divers intentionally touching the substrate were omitted from analyses. Instances of divers touching substrates described below therefore only relate to unintentional touches, unless stated otherwise.

3. Results

During 47 dives, we observed the behaviour of 66 divers (50 recreational divers and 16 guides). The average age of divers was 45.6 years old (±SE 1.6 years), and 59.1% of divers were male, 40.9% female. Recreational divers were highly experienced, with an average total of 741 logged dives (±SE 137 dives). Dive guides had an average total of 4053 dives (±SE 960 dives). Three recreational divers (6%) had entry level certification, compared to 23 divers (46%) with a higher certification and 25 divers (48%) with a professional certification. Twenty recreational divers (40%) did not use a camera, 25 (50%) had a compact camera and six divers (10%) used a dSLR camera.

On coral reefs, the substrates that divers touched most often were sand and corals, compare to sand and sponges on muck sites. Intentional contacts with the substrate were made most often with muck sticks, whereas unintentional contacts occurred most frequently with dive equipment. Damage to the substrate was caused mostly by fins. When divers touched animals, they mostly used muck sticks.

3.1. Effect of activity on diver behaviour

We made standard observations for all 66 divers and observed a total of 236 interactions with cryptobenthic fauna. During the standard observations divers touched the substrate 585 times, compared to 1362 times during the interactions (Detailed table of contact frequencies in Supplementary materials). The frequency with which divers touched the substrate was more than three times higher during interactions than during standard observations (W: $p < 0.001$, $V = 103$; Fig. 1A). Divers also made three times as many unintentional contacts with the substrate during interactions than during standard observations (W: $p < 0.001$, $V = 187.5$; Fig. 1A). There was no significant difference between the frequency of damage during interactions and standard observations (W: $p = 0.35$, $V = 43$; Fig. 1A). As expected, divers touched animals more frequently during interactions than during standard observations (W: $p < 0.001$, $V = 0$; Fig. 1A).

During interactions, the activity that divers were engaged in had a significant effect on the frequency of unintentional contact with the substrate (KW: $p < 0.001$, $df = 2$, $\chi^2 = 16.2$) and on the frequency of touching animals (KW: $p < 0.001$, $df = 2$, $\chi^2 = 17.6$; Fig. 1B). Divers made three times more unintentional contacts with the substrate when photographing cryptobenthic fauna than while observing (W: $p < 0.001$, $V = 77$) or showing animals (W: $p = 0.001$, $W = 52$; Fig. 1B). There was no difference in the number of unintentional contacts between observing and showing animals (W: $p = 0.81$, $W = 150$). Divers touched animals six times more frequently while showing them to other divers than while photographing them (W: $p = 0.02$, $W = 214$), and divers did not touch animals while observing (W: $p < 0.001$, $W = 63$; Fig. 1B). Photographers touched animals more frequently than divers that were observing animals (W: $p = 0.02$, $W = 157$; Fig. 1B). Diver activity during interactions had no statistically significant effect on the total instances of substrate being touched (KW: $p = 0.07$, $df = 2$, $\chi^2 = 5.5$) or on instances of damage (KW: $p = 0.97$, $df = 2$, $\chi^2 = 0.1$).

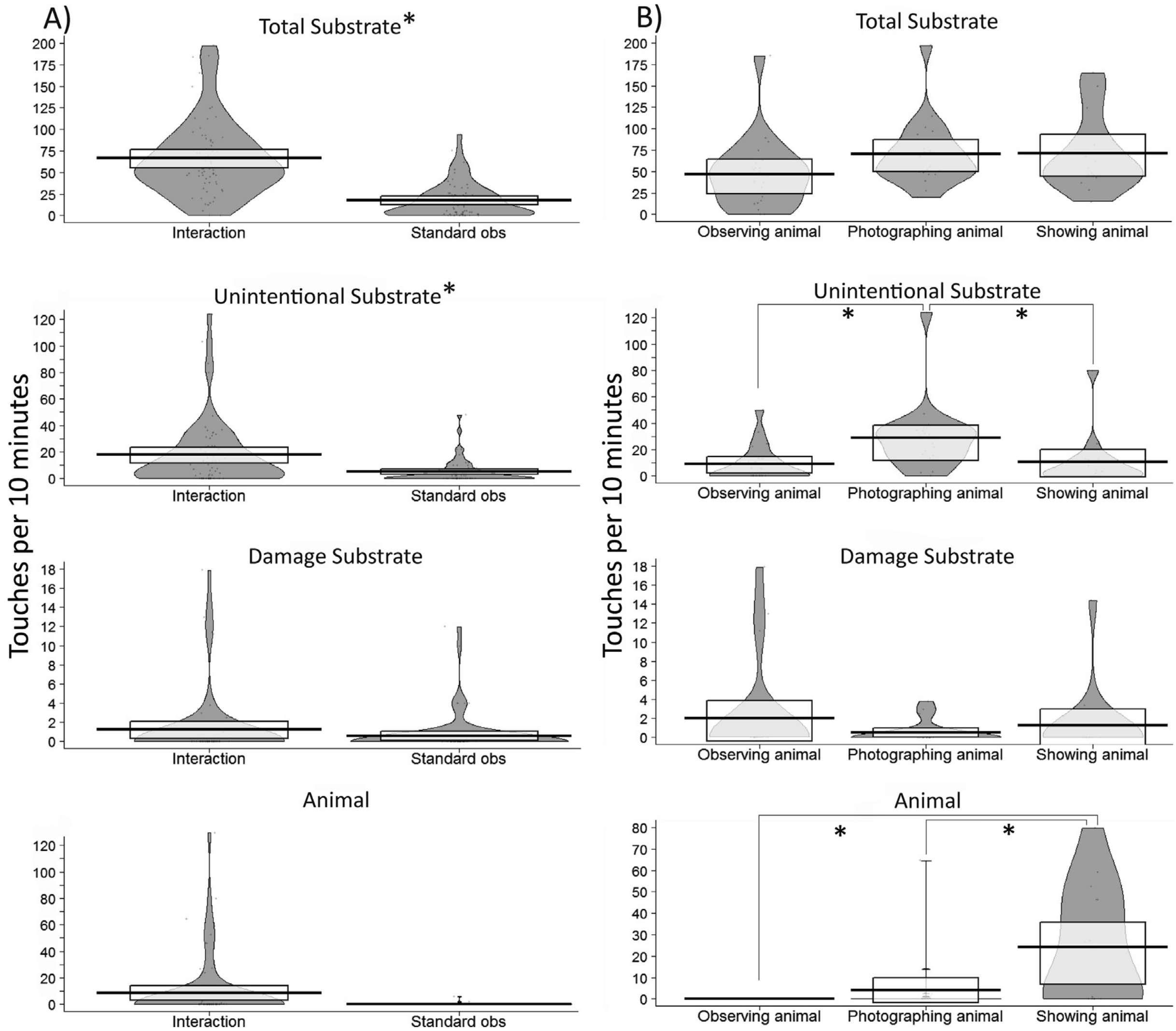

Fig. 1. Pirate plots of the frequency divers touched the substrate (total and unintentional), caused damage to the substrate and touched animals, * indicates significant differences, black bar indicates mean, white rectangle shows 95% confidence interval, beans represent density. A: Comparison between standard observations and interactions with cryptobenthic fauna. B: Comparisons between diver impacts during different types of cryptobenthic fauna interactions: observing, photographing and showing.

3.2. Effect of habitat on diver behaviour

Thirty divers were observed on coral reefs and 49 divers on muck dive sites. During standard observations divers touched the substrate on coral reefs less than half as often than on muck dive sites (W: $p = 0.02$, $W = 315$; Fig. 2A). There was no effect of habitat on the number of unintentional contacts, damage done or animals touched during standard observations (Fig. 2A). During interactions with cryptobenthic fauna, the type of habitat had no significant effect on any of the impacts of diver behaviour that we recorded (Fig. 2B).

3.3. Effect of camera use on diver behaviour

During standard observations, using a camera had an effect on the number of times divers had unintentional contacts with the substrate (KW: $p = 0.02$, $df = 2$, $\chi^2 = 8.34$), and the number of instances of damage caused (KW: $p = 0.04$, $df = 2$, $\chi^2 = 6.7$). Divers using compact cameras made unintentional contact with the substrate five times more often than divers without a camera (W: $p = 0.006$, $W = 241.5$), but this was not significantly different from those with dSLR cameras. Unintentional contacts or damage were not different between divers without a camera and those with dSLR cameras. The divers with compact cameras caused more damage to the substrate than divers without a camera (W: $p = 0.02$, $W = 324$), but there was no difference between compact or dSLR cameras. There was no effect of camera on total number of contacts with the substrate or on the frequency of touching animals during the standard observations.

When divers interacted with cryptobenthic fauna, the use of a camera had a significant effect on the frequency that divers unintentionally touched the substrate (KW: $p = 0.001$, $df = 2$, $\chi^2 = 13.3$), but not on the other variables recorded. Divers without a camera made only one third of the unintentional contacts with the substrate than those with compact cameras (W: $p = 0.002$, $W = 126.5$) and half the contacts of divers with dSLR cameras (W: $p = 0.01$, $W = 29$; Fig. 3B). There was no difference between divers with compact or dSLR cameras (see Table 1).

3.4. Effects of demographics on diver behaviour

During standard observations, the diver's age or the total

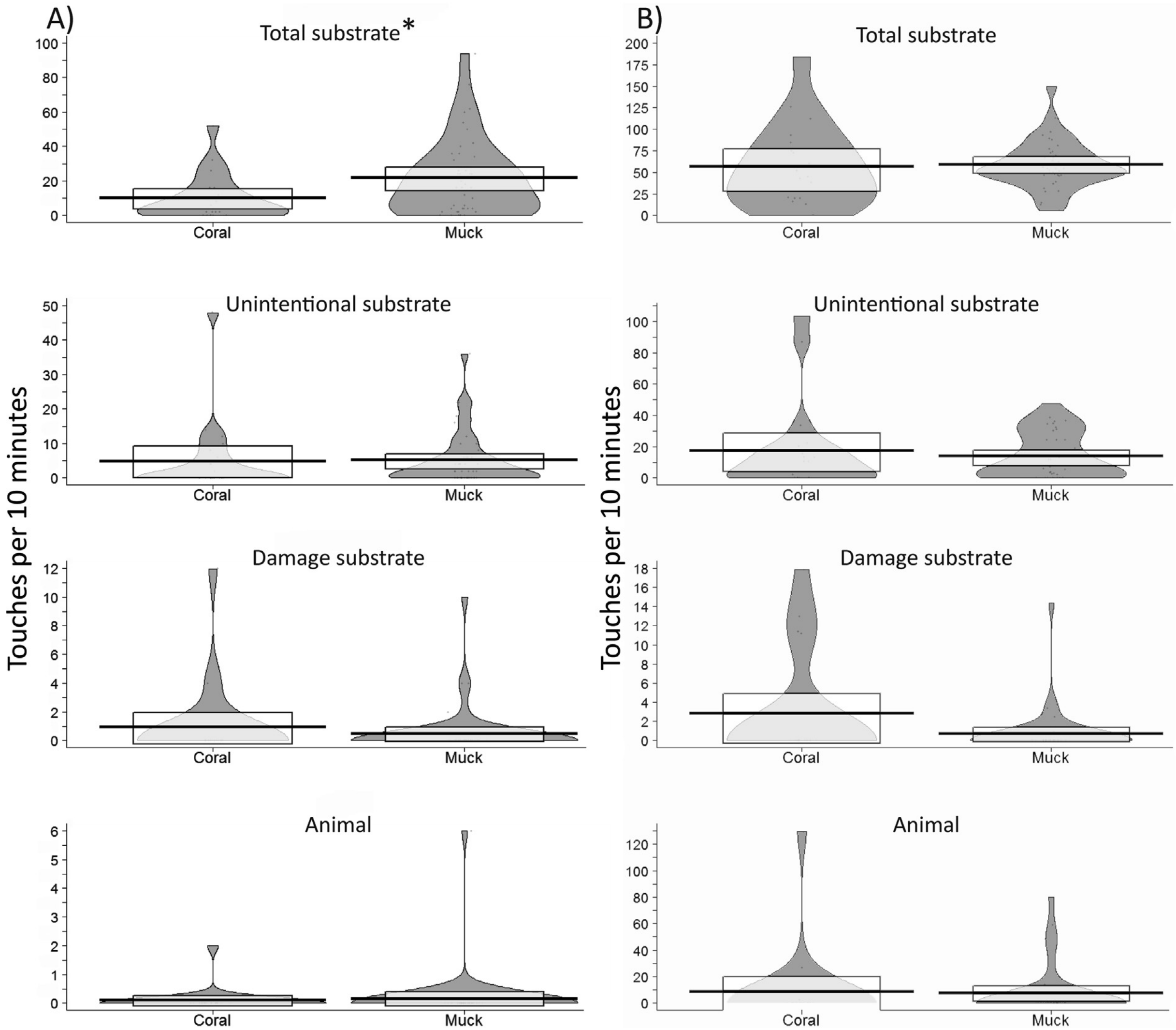

Fig. 2. Effect of habitat on the frequency divers touched the substrate (total and unintentional), caused damage to the substrate and touched animals, * indicates significant differences, black bar indicates mean, white rectangle shows 95% confidence interval, beans represent density. A: Comparisons between coral reef and muck (=soft sediment) habitats during standard observations. B: Comparisons between coral reef and muck (=soft sediment) habitats during interactions with cryptobenthic fauna.

number of logged dives had no effect. Gender affected the number of times the substrate was touched, with males contacting the substrate twice as often as females (KW: $p = 0.003$, $df = 1$, $\chi^2 = 8.7$). A similar pattern was found with the number of unintentional contacts with the substrate (KW: $p = 0.005$, $df = 2$, $\chi^2 = 7.8$). Diver certification level had an effect on the amount of times the substrate was touched (KW: $p = 0.01$, $df = 5$, $\chi^2 = 14.5$) and the damage done to the substrate (KW: $p = 0.02$, $df = 5$, $\chi^2 = 13.1$), with open water divers causing more damage than higher certification levels (Table 2).

During interactions with cryptobenthic fauna, we found no significant effect of diver age or the number of logged dives on any of the variables that were recorded. Male divers touched animals more frequently than female divers (KW: $p = 0.02$, $df = 1$, $\chi^2 = 5.9$). Dive level had a significant effect on the frequency that divers touched animals (KW: $p = 0.002$, $df = 5$, $\chi^2 = 16.2$). Guides touched animals significantly more often than all other levels, except for Open Water Divers (Table 2). There were no significant differences between the other diver levels (Table 2).

3.5. *Duration of diver interactions with cryptobenthic fauna*

The duration of interactions was most strongly affected by the type of camera the diver was using, divers with dSLR cameras spent more time with animals than those with compact cameras or without a camera ($p < 0.001$; Fig. 3; Table 3). The activity divers were doing during interactions had a significant effect on the duration of interactions, divers who were photographing spent more time with animals than those who were observing ($p < 0.001$; Fig. 3; Table 3). Habitat played a role in the duration of interactions, with longer interactions on muck substrates than on coral reefs ($p = 0.012$; Fig. 3; Table 3). The family of the animal that divers interacted with had no significant effect on the duration of interactions ($p = 0.074$; Fig. 3; Table 3).

4. Discussion

Scuba dive tourism can be a sustainable source of income for coastal communities, but has potential drawbacks such as increased damage to fragile reef structures. It is important for management agencies to be aware of diver behaviour to minimise

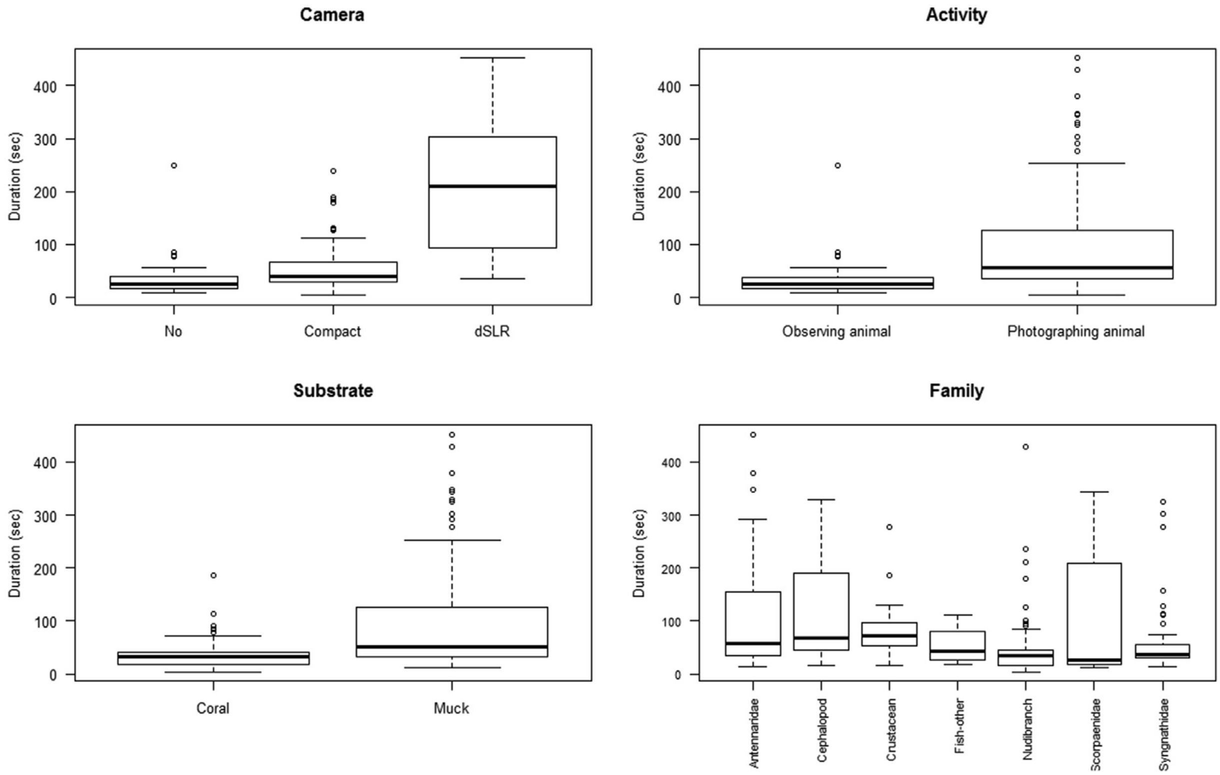

Fig. 3. Effects of camera, activity, habitat and family on the duration divers interacted with cryptic fauna.

Table 1
Most frequently touched substrates by divers and methods of contacting substrates, causing substrate damage and touching animals.

		%	N
Substrate touched	*Coral Reef*		
	Sand	22.7	93
	Hard coral	20.5	84
	Gorgonian seafans	18.8	77
	Soft sediment		
	Sand	84.7	1432
	Sponges	9.5	161
	Rock	4.5	76
Contact method	*Intentional*		
	Muck stick	45	652
	Fins	23.4	339
	Hand	19.6	284
	Unintentional		
	Dive equipment	42.3	278
	Fins	31.5	207
	Muck stick	11.5	74
Damaged by	Fins	47.8	32
	Dive equipment	14.9	10
	Hand / Muck stick	10.5	7
Animals touched with	Muck stick	65.3	128
	Hand	26.5	52
	Camera	4.6	9

detrimental effects to the environment. We demonstrated that normal scuba diver behaviour changes significantly when interacting with cryptobenthic fauna, when diving in different habitats, and when using cameras. Diver certification level and gender also have an effect on behaviour, which should be taken into account when designing management strategies.

The number of divers observed during this study is in line with previously published studies, (see: Chung et al., 2013 (N = 81); Uyarra and Côté 2007 (N = 28); Roche et al., 2016 (N = 100)), however the divers in this study were notably more experienced and older than other studies (Rouphael and Inglis, 2001; Chung et al., 2013; Roche et al., 2016). These high levels of experience are typical for divers participating in muck dive tourism, or interested in cryptobenthic species (Giglio et al., 2015; De Brauwer et al., 2017). Therefore, results of this study are representative for divers in muck dive tourism. The impacts of diver behaviour could be different for less experienced divers on coral reefs, for which a large body of literature already exists (e.g. Chung et al., 2013; Roche et al., 2016).

This study showed the rate that divers make contact with the substrate strongly depends on the type of activity they are doing. When closely observing cryptobenthic fauna, divers approach the substrate more closely than they would during normal dive behaviour. A shift in attention from their surrounding environment to the animal of interest leads to more unintentional contact with the substrate. Divers seemed to be less careful while diving over sand than on coral reefs resulting in significantly more contacts. While this did not result in more observed damage, it is unclear if these disturbances have an impact on soft sediment habitats. The fact that the habitat type of the dive site only affected touch rates during standard observations and not during interactions illustrates the strong effect of diver interactions with cryptic species. Differences between habitats disappeared when divers focused on cryptobenthic fauna, suggesting that divers try harder to avoid fragile coral structures than sand, but that this avoidance behaviour fails when closely approaching small fauna.

These effects were strongest when divers were photographing animals instead of simply observing. Divers made more unintentional contacts with the substrate while photographing, both during interactions and normal dive behaviour. The type of camera a diver used affected how often the diver touched the substrate and how much damage they caused. Divers with compact cameras touched the substrate more often and caused more damage than

Table 2
Posthoc pairwise Wilcoxon tests for effects of diver certification level on touching the substrate and causing damage during standard observations, and touching animals during diver interactions.

Standard: Touching substrate	Open Water	Advanced	Rescue	Divemaster	Instructor
Advanced	0.13	–	–	–	–
Rescue	0.19	0.80	–	–	–
Divemaster	0.16	0.52	0.26	–	–
Instructor	0.25	0.29	0.38	**0.04***	–
Guide	0.40	**0.02***	**0.02***	**0.002****	0.16
Standard: Damage substrate	**Open Water**	**Advanced**	**Rescue**	**Divemaster**	**Instructor**
Advanced	0.24	–	–	–	–
Rescue	0.19	1.0	–	–	–
Divemaster	**0.007****	0.17	0.18	–	–
Instructor	**0.04***	0.45	0.49	0.40	–
Guide	**0.001****	0.09	0.11	–	0.29
Interaction: Touching animals	**Open Water**	**Advanced**	**Rescue**	**Divemaster**	**Instructor**
Advanced	0.15	–	–	–	–
Rescue	0.40	0.41	–	–	–
Divemaster	0.40	0.41	1.0	–	–
Instructor	0.31	0.45	1.0	0.88	–
Guide	0.26	**0.009****	**0.01***	**0.02***	**0.008****

Bold values represent results that are significant at $p < 0.05$.

Table 3
Results of Repeated Measures ANOVA testing for effects of camera, activity, habitat and family on the duration divers interacted with cryptic fauna, using Diver ID as Random Factor in null model.

Factor	AIC	StdDev (log10)	P-value
Diver ID (null model)	127.6	0.081	
Camera	88.9		**< 0.001*****
Intercept (None)		1.43	
Compact		0.182	
dSLR		0.819	
Activity	113.7		**< 0.001*****
Intercept (Observing)		1.466	
Photographing		0.285	
Habitat	123.3		**0.012***
Intercept (Coral)		1.512	
Muck		0.188	
Family	128.1		0.074

Bold values represent results that are significant at $p < 0.05$.

those with dSLR cameras during normal dive behaviour. This difference could potentially be attributed to the fact that dSLR cameras are used by more experienced divers than compact camera users, allowing them to pay more attention to their environment as well as their camera (Roche et al., 2016; De Brauwer et al., 2017). However, during interactions, differences between camera types disappeared, again highlighting the strong effect of divers' attention being diverted elsewhere. A limitation of this study is the small number of divers using dSLR cameras, further study focused on the behaviour of photographers using dSLR cameras is therefore suggested.

Photography also had a strong effect on how long divers interacted with wildlife, and was more important than the actual species they were interacting with. Divers with cameras spent up to ten times longer with animals than those who were merely observing. While this did not always result in more damage to the substrate, long interaction times could negatively affect the animals that are observed, particularly when divers also touch the animals. Divers showing cryptic animals to other divers touched animals most frequently, often using muck sticks or hands to coax animals into a better position to take a photograph. Muck sticks are used frequently to avoid injury from potentially dangerous species such as *Scorpaenidae* and blue ringed octopus (*Hapalochlaena* spp.). However, muck sticks can cause considerable damage to animals. On multiple occasions the authors observed crustaceans and crinoids suffering severed appendages from muck sticks. Previous studies have shown that touching animals can be stressful to cryptobenthic fauna and can lead to short-term behavioural changes (Harasti and Gladstone, 2013). The continuous manipulations by large numbers of divers (up to 300/day on popular sites in the surveyed regions) are likely to cause chronic stress in slow-moving animals such as seahorses or frogfishes.

Confirming previous studies, divers in this study touched the substrate most frequently and caused the most damage with their fins and loose hanging dive equipment such as submersible pressure gauges or alternate air sources (Barker and Roberts, 2004; Roche et al., 2016). During normal dive behaviour, male divers made more contact with the substrate than females and beginner divers caused more damage than experienced ones. This difference could be attributed to males being more prone to taking risks, or less likely to follow dive guide instructions (Luna et al., 2009). Similar trends have previously been reported on the Great Barrier Reef (Rouphael and Inglis, 2001), but are different from Uyarra and Côté (2007) which found that female divers caused more damage. Differences between genders or certification levels disappeared when interacting with cryptobenthic fauna, another clear indication that these interactions are strong drivers of diver behaviour. The only diver level-based difference during interactions was that dive guides touched animals more frequently. Dive guides are paid to find and show animals to divers. With this economic incentive, guides undoubtedly feel the pressure of delivering 'good' customer service to divers wanting to observe or photograph rare cryptic species.

Divers in this study caused limited damage to the substrate per individual, yet with the high numbers of dive tourists on some sites, the accumulated effects will be significant. Furthermore, potential negative impacts caused by flash photography, remain unknown and should be investigated to assist in management of dive tourism (Harasti and Gladstone, 2013). Mitigating the impacts divers have on fauna or substrates is therefore paramount. Adequate buoyancy training is essential to avoid accidental contacts with the substrate, but is not always sufficient in avoiding impacts during interactions. Pre-dive briefings can significantly reduce the impacts of divers on coral reefs (Camp and Fraser, 2012). Dive guide interventions during the dive are even more effective at preventing damage than dive briefings (Barker and Roberts, 2004; Roche et al., 2016). The question remains whether dive guide interventions are a viable option in the specialised muck dive industry, with its strong emphasis on photography. Cultural differences and a dependence on tips earned by satisfying customer requests to find interesting fauna create strong barriers for dive guides to intervene when their divers are behaving unethically. Dive guides require support from management coupled with education about the potential impacts, empowering them to respond to unethical behaviour. However, it is even more crucial for divers to be educated and made aware of their own impacts, as an awareness of impacts on animals has been shown to increase tourist willingness to make trade-offs that increase animal welfare (Bach and Burton, 2017). Alternative regulations such as temporary closures of dive sites or limiting the maximum number of divers per site have been suggested and in some case successfully implemented (Zhang et al., 2016). Effective management is crucial, but is the current regime of self-regulation in dive tourism sufficient to address its impacts?

To ensure efficient management, we suggest the following guidelines:

1. Increased education for recreational divers and dive professionals about the impacts of unethical diver behaviour. This can be achieved during dive briefings or integrated with diver training using specialised programs for dive centres such as Green Fins, but needs the support of dive centre management to be successful (Roche et al., 2016). Education should include scientifically supported evidence explaining why certain behaviour is discouraged (Scott-Ireton, 2008; Camp and Fraser, 2012; Bach and Burton, 2017).
2. Integrating all stakeholders in the development of a region-specific code of conduct. Stakeholders beyond dive tourism should be involved to create a wider support base (Dimmock and Musa, 2015). Regional differences need to be taken into account to ensure successful implementation of codes of conduct and to empower dive guides to take action under water (Wongthong and Harvey, 2014).
3. Increased awareness of scuba diver and wildlife photography impacts on a global scale. The competitive aspects of photography offers avenues to influence divers' attitudes concerning wildlife photography. Clear rules from the organising committees of photo competitions to no longer accept unethical behaviour would send a powerful signal. Large dive expos, dive magazines and wildlife photography publishing agencies such as National Geographic can fulfil a role-model function by not publishing images that are clearly the result of photographer manipulation.

5. Conclusion

This research adds to a growing body of literature that explains diver behaviour and its potential impacts on the natural environment. It shows that the activity divers are undertaking under water has a larger impact on their behaviour and associated environmental damage than their demographic profile. Divers interacting with cryptobenthic fauna, particularly photographers, have a higher impact on the substrate and touch animals more frequently than non-photographers. The frequent touching of animals and often extended periods of time divers spend with individual animals is likely to cause significant stress and requires the attention of management bodies, and targeted research. While underwater photography can be a powerful tool for conservation outreach, care needs to be taken that photography remains sustainable. The increased impacts of divers during interactions with cryptic fauna could be mitigated by increased education, and improved management practices including the development of region-specific codes of conduct. But, strong support from dive certification organisations, publishing houses that specialise in underwater photography, and the tourism industry is essential to ensure successful implementation. While there are significant challenges associated with managing scuba diver impacts, the economic contributions of dive tourism to local communities highlight the importance of striving for increased sustainability of the industry.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2018.04.047.

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