Benthic impacts of recreational divers in a Mediterranean Marine Protected Area

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The features of many Marine Protected Areas (MPAs) have increased scuba diving tourism in these areas. Impacts caused by recreational scuba activity vary widely among different divers with differing underwater behaviour. We studied diver underwater behaviour, the effects on the natural environment, and the characteristics that may influence diver behaviour. In all, 181 recreational divers were followed, and contacts and the effects produced were recorded. Information on diver profile and dive features was recorded. Field sampling revealed that 175 of the divers observed (96.7%) made at least one contact with the seabed, with a mean contact of 41.20 ± 3.55 (mean $\pm$ s.e.) per diver per 10 min. Flapping was the most frequent type of contact, and the main damage by this action was to raise sediment. Contact with the seabed was greater for males than for females, inexperienced divers than for experienced divers, camera or lantern (dive light) users than for non-users, and divers unaccompanied by a dive leader or who had not been briefed about avoiding seabed contact before undertaking a dive than for accompanied or briefed divers. A greater understanding of the causes of harmful behaviour may be useful for stricter management, reducing diving damage and assuring the sustainability of this activity in MPAs.

Keywords: diver damage, management of scuba diving, Marine Protected Area, MPA, recreational impact.

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Introduction

For decades, the creation of Marine Protected Areas (MPAs) has been considered to be the only way to restore natural communities and to protect marine ecosystems (Milazzo *et al.*, 2002). New MPAs are being established around the world (Ballantine, 1995), and "marine-based" tourism is a rapidly growing industry (Ribera, 1991; Boudouresque and Ribera, 1995; Davis and Tisdell, 1995). The aesthetic appeal of MPAs and the facilities they provide, together with the increased public awareness of nature, all contribute to creating massive tourism in MPAs (Ribera, 1991; Richez, 1991, 1992, 1993; Capellà *et al.*, 1998; Badalamenti *et al.*, 2000).

In the past 20 years, the number of visits to MPAs has increased globally (Dixon *et al.*, 1993; Hawkins and Roberts, 1994; Kelleher *et al.*, 1995), with an associated increase in the rates of participation in marine recreational activities, such as snorkelling, scuba diving, or boating (Tabata, 1989, 1992; Dignam, 1990; Marion and Rogers, 1994; Davis and Tisdell, 1995). New technology and the consequent safety improvements have greatly increased the number of recreational divers (Davis and Tisdell, 1995), as well as the extent of this activity around the world (Hawkins and Roberts, 1992).

Scuba diving may result in the deterioration of benthic communities, because divers can easily damage marine organisms through physical contact with their hands, body, equipment, and fins (Talge, 1992; Rouphael and Inglis, 1995, 1997; Tratalos and Austin, 2001; Zakai and Chadwick-Furman, 2002; Pulfrich *et al.*, 2003; Uyarra and Côté, 2007). Although the damage produced by individuals is usually minor, there is some evidence that the cumulative effects of the disturbances can cause significant localized destruction of sensitive organisms (Garrabou *et al.*, 1998; Hawkins *et al.*, 1999; Plathong *et al.*, 2000). There is a bigger problem when the diving activity focuses on MPAs. In some cases, the effects of a large number of divers in a few places in a marine reserve can be contrary to the main objectives of the creation of the MPA (Davis and Tisdell, 1995, 1996; Coma *et al.*, 2004; Hawkins *et al.*, 2005). However, some authors state that the impact of divers at a site may be influenced more by their experience and behaviour than by the number of people who frequent the site (Davis and Tisdell, 1995; Rouphael and Inglis, 2001; Barker and Roberts, 2004).

The relationship between diver behaviour and their impact on marine communities has been widely studied in coral reef areas (Caribbean, Red Sea, Australia), but more seldom in temperate systems. The main objectives of our study were to (i) characterize diver behaviour according to a diver profile, and (ii) evaluate and quantify their effects on the Mediterranean benthic community. We provide an estimate of the damage rate of divers on the benthic communities, demonstrate the relationship between diver behaviour and profile, and the dive characteristics, and illustrate the most important damaging factors to propose educational tools to help reduce the negative effects.

Material and methods

Study area

The study was carried out at the Sierra Helada Marine Park (SHMP; 4920 ha), which is located between Altea and Benidorm

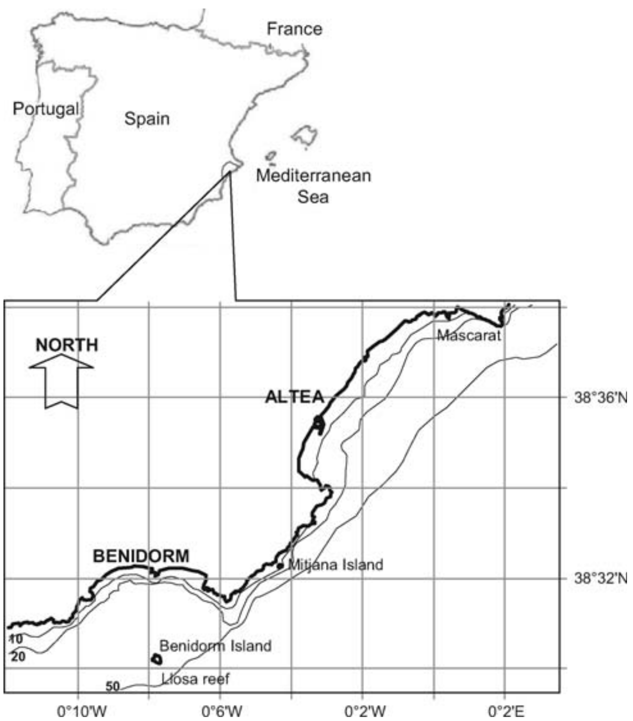

Figure 1. Sampling area location.

(Alicante, Spain; Figure 1) and includes the Benidorm and Mediana Islands, the Galera and Olla reefs, the surrounding waters, and the adjacent mainland coast. The *Posidonia oceanica* seabed in the Sierra Helada Marine Park seems to be in an optimum state of health, and *Cystoseira* seabed, rocky coralligenous, maërl, and cave habitats are also well represented.

The physical and biological characteristics in and surrounding the SHMP are very important for marine recreation, and activities there have increased in recent years. The number of divers increased from 10 775 in 2005 to >24 000 in 2006 (Coselleria Territori i Habitatge), and there was strong seasonal and spatial concentration, with 13 336 divers in summer 2006 (55.4% of the annual total) visiting just three sites.

Sampling diver behaviour

In all, 181 scuba divers were followed at the most popular places in the park (Llosa Reef, Benidorm Island, and Mitjana Island) between July and September 2006. Divers were selected randomly from visiting groups and discreetly observed for 10 min each. The 10-min observation period was determined, from pilot studies, to be the most cost-effective for observing a large number of divers with the available resources (Rouphael and Inglis, 1997). The monitoring of divers started 10 min after their entry into the water, and after the divers adjusted their equipment and buoyancy.

On each dive, the number and the duration of contacts with the seabed were noted, as well as which part of the diver (hand, body, or knee) or equipment (tank, fins, camera, light, i.e. lantern, or octopus) was involved in the contact. The number of times a diver flapped fins, collected or handled organisms, fed organisms, or turned over rocks was also recorded during observation periods. For all actions, the consequences of this contact (raising sediment, contact with fragile species, or removal of algae) were reported.

Observers remained in the water behind their target divers, with visual contact (~4–5 m away), so as not to influence diver behaviour. The observations were interrupted when the target diver modified his or her behaviour as a consequence of the presence of the observers, or when the target divers expressed curiosity about the observer's work. We determined the influence of diver characteristics on their underwater behaviour. After each dive, target divers were asked about their diving experience, gender, age, and perception of the damage of scuba diving. Finally, we collected information on 11 factors that may influence diver behaviour underwater.

The factors that may influence diver behaviour were assessed separately (Table 1): (i) gender (male, female); (ii) age (five age groups); (iii) diving qualification (three categories); (iv) total number of dives completed by diver (seven levels); (v) number of years diving (five levels); (vi) whether or not a briefing was given; (vii) the presence of the centre diving guide during a dive; (xiii) the diving depth (three levels of depth); (ix) use or not of a camera; (x) use of a lantern for lighting; and (xi) perception of the diving damage on the marine environment.

Statistical analyses

Differences in the mean frequency of contacts for each main factor were examined by one-way analysis of variance (ANOVA). For each factor, we evaluated three independent variables: the

Table 1. Factors influencing diver behaviour and assessment level.

Factor	Level
Diver factors	
Gender	Male
	Female
Age (years)	1: <31
	2: 31–35
	3: 36–40
	4: 41–50
	5: >50
Diving qualification	1: Beginner
	2: Moderately
	3: Expert
Years diving (years)	1: <1
	2: 1–2
	3: 3–5
	4: 6–10
	5: >10
Number of dives	1: <6
	2: 6–12
	3: 13–24
	4: 25–50
	5: 51–100
	6: 101–200
	7: >200
Perception of damage	Yes
	No
	No answer
Dive factors	
Depth (m)	1: <12
	2: 12–20
	3: >20
Leader	Yes or no
Briefing	Yes or no
Camera	Yes or no
Lantern	Yes or no

number of contacts with any part of the equipment and the body, and the total number of flapping events.

Before ANOVA, heterogeneity of variance was tested with Cochran's *C*-test. Data were $\sqrt{(x+1)}$ transformed if variances were heterogeneous, followed by $\ln(x+1)$ transformation if necessary. Where variance remained heterogeneous, non-transformed data were analysed, because ANOVA is robust to heterogeneity of variance, particularly for large, balanced experiments (Underwood, 1997). In those cases, we used a more strict significance level ($p < 0.01$).

Results

Of the 181 divers followed and interviewed immediately after diving, there were more men (72.9%) than women, and the ages ranged from 18 to 69 years. The mean age group for both genders was the same, 30–40 years. The percentages of men and women sampled within each age category were similar.

Most divers had beginner (44.7%) or medium-level dive qualification (42.0%); just 13.3% had expert level. Of the total number of divers observed, 20 (11%) were photographers and 44 (24.3%) used a lantern during their dive.

Effects of diver behaviour

Of the 181 divers observed, 175 (96.7%) made at least one contact with the seabed, with a mean of 41.20 ± 3.55 (mean $\pm$ s.e.) contacts per diver per 10 min. Flapping was the most frequent type of contact. On average, each diver made 32.56 ± 3.24 flapping contacts per 10 min ($n = 5894$ contacts), and the main observed consequences or damage were the raising of sediment (58.3%) and the removal of algae (38.1%).

The mean number of contacts with any part of the equipment and any part of the diver was similar at 4.30 ± 0.35 and 4.34 ± 0.44, respectively. The type of contact varied with equipment part. Contact with fins accounted for the greatest proportion (78.5% of contacts; $n = 778$), with a mean per dive of 3.37 ± 0.30 and a duration of 8.90 ± 0.87 s per contact with fins. The most common consequence was the trampling of organisms (27.6% of 611 contacts), resuspension of sediment (25.2%), and the removal of algae (20.0%). The second element causing damage, with a total of 127 contacts, was alternative air sources ("octopus") or manometer, with a mean per dive of 0.70 ± 0.12, and the most frequent effect of this activity was the resuspension of sediment (30.0%) and the removal of algae (26.8%). Contact with other elements, tank, camera, or light, was less common during the dives, but tank contact time was high (11.91 ± 2.55 s per contact).

For contacts with any part of the body ($n = 786$), the most frequent was contact with the hands (3.0 ± 0.32 per diver per 10 min, with a duration of 9.38 ± 0.85 s). The total number of contacts with hands was 539, and it usually involved trampling of organisms (43.2%), contact with fragile organisms (22.8%), and the raising of sediment (21.7%). The divers made 1.20 ± 0.19 contacts per 10 min with their knees ($n = 218$ in all), with a mean duration of 14.47 ± 2.10 s. The most common effects were trampling the organisms and removing the algae (51.0 and 5.6%, respectively). Although contact with the whole body when lying on the bottom was infrequent (0.16 ± 0.04 per dive of 10 min), the contact was longer (23.25 ± 6.87 s per contact). Trampling of organisms (34.5%) and the resuspension of sediment (31.2%) were the most common results of whole body contact ($n = 29$).

While divers are taking photos, they usually rest another part of their body or their equipment on the seabed, so a mean of 5.14 ± 0.90 contacts per 10 min was recorded, with a mean duration of 31.84 ± 25.04 s. This action made contact with fragile organisms (30.5%), and 19.4% caused trampling and removal of algae.

Divers who carried lanterns during their dive had similar behaviour to that observed for photographers. The divers with lanterns made 2.69 ± 0.66 contacts per 10 min, with an average time of 23.98 ± 11.20 s. Contact was made with fragile organisms in 54.3% of the total number of lantern contacts, and 17.1% caused trampling of organisms or raising of sediment, in the same proportion.

During the dives sampled, handling for organism recognition was observed 17 times, with an average duration of 30.72 ± 9.50 s. Octopuses were the organisms most frequently disturbed by divers, followed by snails, sea stars, and crabs. Collecting of organisms by divers was observed five times, 2.3% of the total number of divers. The divers collected small snails and one *Myriapora truncata* colony. Stone-turning was only observed seven times and was caused by inadvertent use of the fins.

Diver behaviour according to profile

There was a significant gender difference (Figure 2) in the number of damaging contacts on the seabed. Female divers caused proportionally fewer contacts than males, but these differences were significant only for flapping ($p < 0.001$) and contacts with any part of the body ($p < 0.05$). The age of divers did not have a significant effect on behaviour, and no trend was observed between age and the number of contacts (Figure 3a). Diver qualification did not have a significant effect on the number of contacts (Figure 3b), but experience (number of completed dives; Figure 3c) and years diving (Figure 3d) were significant. The most experienced divers, who had more dives completed or more years of diving, made statistically fewer contacts. These differences in the two factors were significant for flapping ($p < 0.001$) and for contact with any part of the diving equipment ($p < 0.001$).

The divers who did not perceive any ecological damage by scuba diving (26%) or who did not answer the question (9.4%) made more contacts with the substratum than divers who thought that scuba could cause ecological damage (Figure 3e). Flapping was the best variable for detecting these differences ($p < 0.05$).

Diver behaviour according to dive features

When the diving profile was analysed, the depth recorded did not show any significant differences in diver behaviour, although

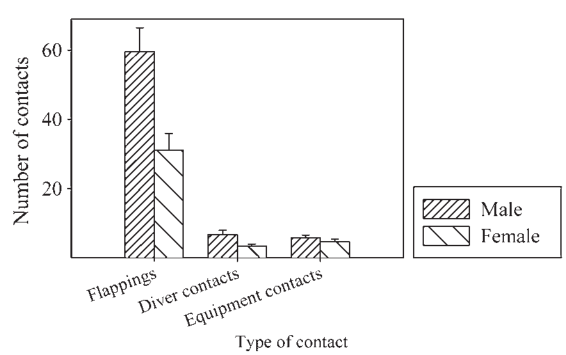

Figure 2. Mean number of contacts by diver gender. Error bars indicate 1 s.e.

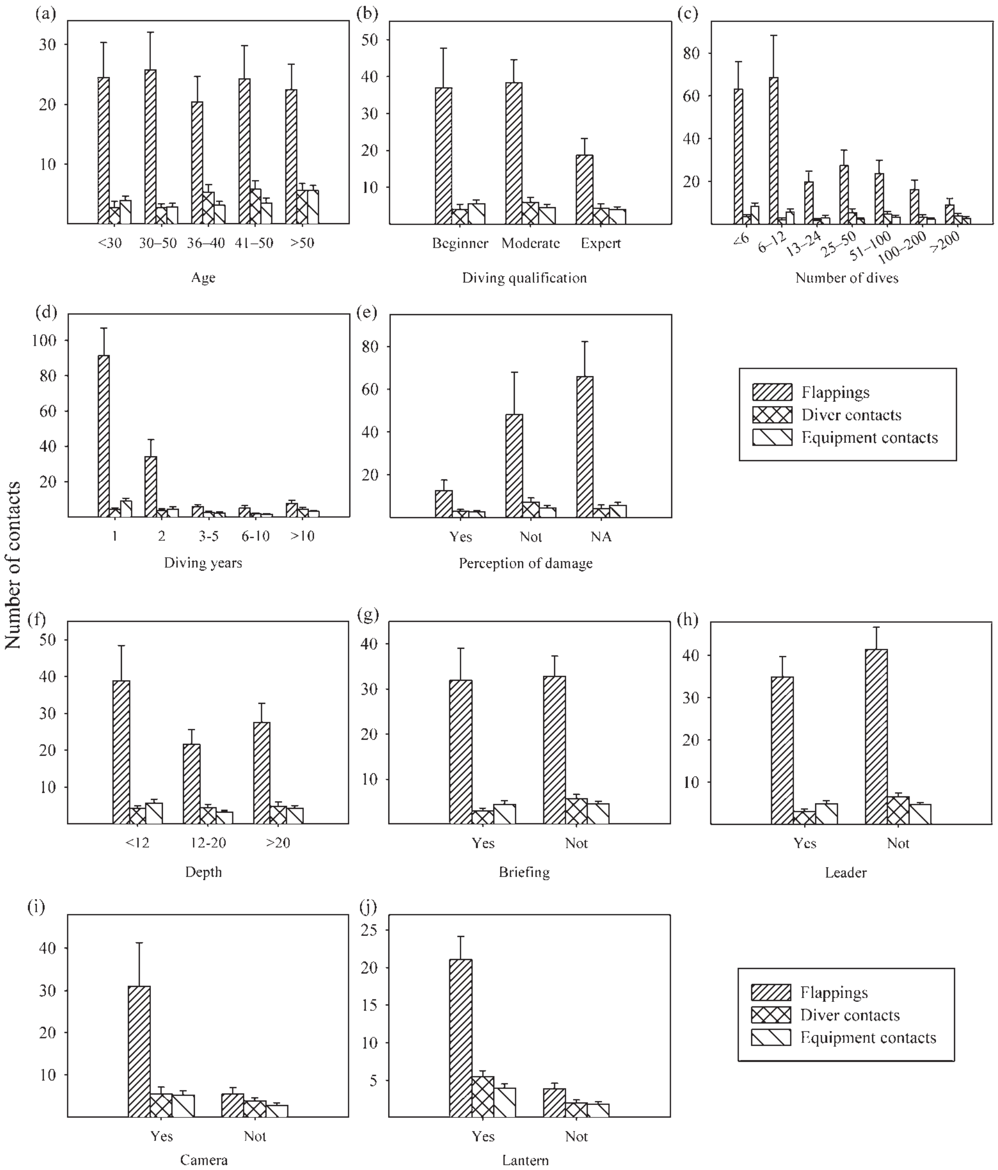

Figure 3. Mean number of contacts according to diver profile and dive feature. Error bars indicate 1 s.e.

contacts by any part of the body were more prevalent in deeper dives, as were flapping and contact by equipment (Figure 3f).

The effect of a previous briefing by a senior member of the diving club significantly reduced ($p < 0.01$) the diver contact rates for flapping and contact with any part of the body (Figure 3g). Although no significant differences were found, contacts by any part of the diving equipment were also fewer. Similarly, when the dive was guided by a diving leader, flapping and the number of contacts with any part of the body were less (Figure 3h), although only the decrease in contacts with any part of the body was significant ($p < 0.01$).

Underwater photographers made contact with the seabed more frequently than non-camera users (Figure 3i), mainly through flapping ($p < 0.05$) and contact by parts of the equipment ($p < 0.01$). The divers carrying lanterns (Figure 3j) were normally closer to the seabed, looking for holes, fissures, etc., and made more contacts than non-lantern users for the three variables considered ($p < 0.001$).

Discussion

Identifying the different factors that describe diver behaviour and their environmental effects may help managers to develop more-effective training procedures, pre-dive briefings, site regulations, etc., to prevent or reduce the incidence of damaging behaviours (Rouphael and Inglis, 2001). For this reason, we evaluated the relationships between factors that could influence underwater behaviour and showed the existence of several intrinsic diver and dive factors that may influence the effects of scuba diving. Contact frequency with the seabed is strongly influenced by diver profile and immersion characteristics.

By following divers, we showed that 96.7% of them made some contact during the 10 min immersion, causing potentially serious damage to the environment. This rate is consistent with other works on scuba-diver impacts (Rouphael and Inglis, 2001; Uyarra and Côté, 2007), most divers (90, 70, and 75%, respectively) making one or more interactions with the substratum. We estimate that in a 45-min immersion, each recreational diver may make 100 interactions resulting in the raising of sediment, more than 60 removing algae, 8 contacts with fragile organisms, and 14 contacts that result in the trampling of organisms. The other observed effects would be less frequent.

Most contacts were caused by flapping and contact with fins, confirming similar results from the Red Sea (Prior *et al.*, 1995; Zakai and Chadwick-Furman, 2002), Australia (Roberts and Harriot, 1994; Harriot *et al.*, 1997; Rouphael and Inglis, 2001), and the Caribbean (Barker and Roberts, 2004; Uyarra and Côté, 2007), which attribute most diver damage to the effect of fins. The hands were the part of the body that made most impacts, as also observed for divers in the Red Sea (Zakai and Chadwick-Furman, 2002) and the Caribbean (Barker and Roberts, 2004; Uyarra and Côté, 2007). Most contacts appeared to be unintentional and caused by poor swimming technique, incorrect weighting, and lack of warning, factors that, in general, indicate a poor diving proficiency.

There were gender differences in the contact frequency for flapping and contact with any part of the body, women causing fewer impacts than men. In general, a male diver is less cautious in his underwater behaviour, tending to be more adventurous and more likely to take risks than women, a relationship also shown by other studies of environmental attitudes and the behaviour of male and female divers (Hudgens and Fatkin, 1985; Vredenburgh and Cohen, 1993; Rouphael and Inglis, 2001). Another explanation for this result is that men are more likely to ignore pre-dive instructions on safety and environmental behaviour advice than women, having a more independent attitude, an observation made also by others (Vredenburgh and Cohen, 1993).

The effect of diver experience on the number of impacts has been documented in some areas (Roberts and Harriot, 1994), but not in others (Harriot *et al.*, 1997; Rouphael and Inglis, 2001), but these differences could be because of differences in the definitions. In our study, diving experience was measured through three variables: level of the diving certificate, the total number of dives, and the number of years diving. Both total number of dives and the years of diving were associated with environmental impact, less damage being caused by the more experienced divers. The diving certificate level did not show this association, so it does not appear to reflect diving experience. A diver can obtain a higher certification by taking an advanced course, but this does not mean that the person becomes more proficient. Divers can even become diving instructors with fewer than 100 immersions. Dive-training certificates are lifetime qualifications and do not require periodic renewal or dive proficiency testing. Therefore, diver training level may not be a good indicator of current diving skills, and this factor is not sufficient to determine whether a diver is qualified for diving at a site. This topic needs to be considered when adopting management strategies in dive areas.

Briefings before the dive and underwater intervention by a dive leader were highly effective at reducing the average impact of flapping and contact by any part of the body, as found in other studies (Medio *et al.*, 1997; Barker and Roberts, 2004; Uyarra and Côté, 2007). These differences in dive behaviour were more obvious for intentional contacts by any part of the body, confirming that deliberate contacts may be reduced by the implementation of simple measures by the diving centres. Attending a briefing emphasizing the importance of buoyancy control and careful action (educational tools) increases the environmental awareness of recreational divers and might reduce diver damage at dive sites. Moreover, the use of dive leaders during dives is a clearly effective tool in minimizing scuba divers' physical impact on their environment, because dive leaders can take measures when they see divers behaving inappropriately. For this reason, smaller dive groups tend to be better, dive leaders being able to supervise all members of the group adequately (Barker and Roberts, 2004). In any case, smaller groups are preferred by the divers themselves.

Control of instruments used at the most fragile sites by divers, such as cameras or lanterns, may be a good measure for controlling damage by scuba diving, because carrying any element causes divers to have a greater interaction with the environment than when divers carry nothing. This finding, in terms of photographers, has been observed in other studies (Medio *et al.*, 1997; Rouphael and Inglis, 2001; Barker and Roberts, 2004; Uyarra and Côté, 2007), but the effect of carrying lanterns has not been evaluated before. The photographers being observed tended to adopt the most comfortable and best position to avoid movement and to obtain better images. They then cause damage by anchoring themselves at the bottom, using their knees, fins, elbows, etc. When carrying a lantern, divers exhibit a particular behaviour, looking for small holes, cracks, caves, or animals to illuminate, and they often disregard their buoyancy or fail to keep their equipment or body off the seabed.

All these impacts have consequences for the benthic community at the most popular dive sites of the SHMP. The area hosts an advanced coralligenous community composed of many sessile, filter-feeding, long-lived organisms with fragile skeletons and slow rates of growth (Laborel, 1961; Ros *et al.*, 1985). The risk of long-term degradation should be determined by the impact rate and the speed with which it is repaired (Rouphael and Inglis, 1997). The problem is that organisms living in Mediterranean coralligenous communities are not adapted to severe disturbance, and their recovery after moderate pressure might be difficult (Garrabou *et al.*, 1998). The sustainability of diving activity at particular sites depends on both the number of divers accessing the sites and the capacity of the ecosystem to regenerate and recover from any damage incurred (Harriot *et al.*, 1997). Monitoring programmes need to be established to detect environmental changes at dive sites before diving impact levels become critical and, perhaps, irreparable.

Management of recreational scuba diving

Divers who were interviewed and saw the negative effects of diving as ecologically critical behaved more carefully, suggesting that diving environmental awareness programmes could be considered. In this sense, managers need to make an effort to teach divers the environmental value and the fragility of different species, as well as show the potential damage of diving activity and how to minimize the negative impact of scuba diving. Diver education programmes ought to include the environmental effects of diving. To improve diver skill, a management agency could require that diving operators attend update courses, pre-dive briefings, and employ a dive leader, to reduce diver impact. Of course, this should also apply to photographers and lantern-carriers.

Diving quotas may also be appropriate in sensitive areas, because the impact at a site is influenced by the number of visitors (Barker and Roberts, 2004). The idea that there is a limit—a "carrying capacity" in terms of human usage—needs to be embraced to ensure that natural resources are not destroyed (Salm *et al.*, 2000). In recent decades, there have been attempts to estimate the carrying capacity of popular dive sites (Davis and Tisdell, 1995), but the results of the estimates vary extensively between different sites around the world, from 5000 to 50 000 divers per site per year (Hawkins and Roberts, 1992; Dixon *et al.*, 1993; Chadwick-Furman, 1997; Harriot *et al.*, 1997; Hawkins *et al.*, 1999; Schleyer and Tomalin, 2000; Zakai and Chadwick-Furman, 2002). The disagreement between the various studies shows that carrying capacity can depend on a combination of many factors, including (i) biological characteristics of the dive site and the presence of vulnerable organisms (Riegl and Cook, 1995; Chadwick-Furman, 1997; Harriot *et al.*, 1997; Rouphael and Inglis, 1997, 2001; Schleyer and Tomalin, 2000; Walters and Samways, 2001), (ii) the underwater activities pursued (Rouphael and Inglis, 1997, 2001; Uyarra and Côté, 2007), (iii) the level of environmental awareness of the divers and their experience or technical competence (Davis and Tisdell, 1995; Medio *et al.*, 1997; Rouphael and Inglis, 1997), (iv) the physical conditions present during a dive, such as wave or current motion (Harriot *et al.*, 1997; Rouphael and Inglis, 1997), (v) the presence of other anthropogenic stressors, such as boat-anchoring (Davis, 1977; Halas, 1985) or pollution (Hawkins and Roberts, 1997), and (vi) the frequency of large-scale natural accidents that may cause deleterious effects, such as events with massive mortality (Nagelkerken *et al.*, 1997; Cerrano *et al.*, 2000; Pérez *et al.*, 2000). Carrying capacity needs to be considered as an elastic factor that should be adapted to communities at each particular dive site and periodically reviewed to enhance its effect. Managers need to note that, although there may be too much emphasis on limiting visitor numbers, other management strategies (e.g. educational programmes) could be used to greater effect (Rouphael and Hanafy, 2007). Our results suggest that there is a need for diving activity managers at the most popular dive sites to maintain and conserve the aesthetic appeal and biological characteristics of their site to achieve sustainable scuba diving attraction.

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