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12 Fighting Invasions in the Marine Realm, a Case Study with *Caulerpa webbiana* in the Azores

12.1 Invasive Marine Species of the Azores

The Azores archipelago, Portugal, is composed of nine small Atlantic islands located in the Northeast Atlantic Ocean over the Mid Atlantic Ridge. The climate is temperate and main currents include a branch of the Gulf Stream.

The first marine non-indigenous species present in the Azores probably arrived with early settlers in the 14th century. The slow sailing ships, with their wooden hulls, were highly prone to fouling by numerous species, including small invertebrates and algae. It is quite likely that the species that have long settled in these islands, and the cryptogenic species, such as the polychaete *Sabella spalanzani*, may have been passively introduced this way. Nevertheless, it is hard to determine how and when they established in the Azores due to lack of records and knowledge of existing fauna and flora in the region prior to the first settlers.

In the late 19th and early 20th centuries, the growing interest in ocean exploration produced baseline information on species diversity and distribution. In the Azores, historical and modern assessments of marine faunal and floral diversity (e.g. Santos *et al.*, 1995; Cardigos *et al.*, 2006) make it possible to trace back arrivals over the last seven decades. This is the case for the algae from the *Asparagopsis* spp. group, which arrived in the Azores around the same time period as when it was first recorded in Europe (late 1920s). Like many other marine species, it is likely that the global increase of maritime traffic in the period between the World Wars contributed to the geographic spreading of this alga.

When considering the likely causes, the first surge of marine non-indigenous organisms arrived with the first settlers, the second movement happened in the beginning of the 20th century associated with the increase of maritime traffic, and the most recent “third wave” of marine non-indigenous species arriving in the Azorean islands is probably linked to the development and growth of world cruise yachting over the last four decades. Unlike the species conveyed in the first two, which were more Europe-centric, species arriving in this third wave have a Caribbean faunal affinity.

Species reaching the Azores in the 21st century seem to be correlated with climatic changes and tropicalization processes (Afonso *et al.*, 2013).

Non-indigenous marine species in the Azores have been listed by Cardigos *et al* (2006). Over the last years, several authors (*e.g.* Afonso *et al.*, 2013; Amat & Tempera, 2009; Cordeiro *et al.*, 2013; Malaquias *et al.*, 2009; Pola *et al.*, 2006; Torres *et al.*, 2010; Torres *et al.*, 2012) identified new occurrences that will certainly increase the list of "alien" species in the Azores, and have studied their routes (Micael *et al.*, 2014).

12.2 History of an Invasion - *Caulerpa webbiana*

The green algae *C. webbiana* (Figure 12.1) was first collected in Faial in 2002. As it was rare and unfamiliar, no special attention was given. Only in 2005, after a significant increase in the total area it covered, a research plan to investigate its biology and ecology was implemented (Amat *et al.*, 2008).

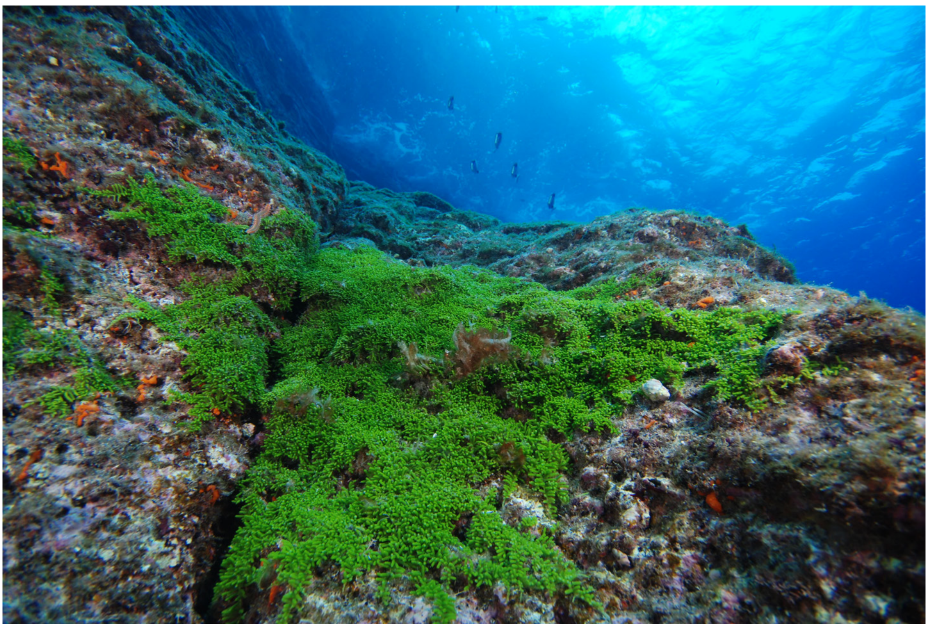

Fig. 12.1: *Caulerpa webbiana* in Faial island (J. Fontes).

Even though this species is not considered invasive elsewhere, the invasive reputation of the genus (Lowe, 2000) and the exponential growth of *Caulerpa* patches made it a matter of concern to local scientists and decision makers. Surveys conducted in the archipelago (2005–2007) suggested that *Caulerpa* was restricted to Horta Bay, in Faial Island. The presence of *C. webbiana* in this limited area surrounding the main harbor and marina of Faial Island, and the higher abundance of the algae in the immediate proximity of the harbor, suggested that this non-indigenous alga arrived using a sailboat or ship as vector (Amat *et al.*, 2008). The preliminary use of molecular tools and genetic analysis did not clarify the origin of the *Caulerpa webbiana* found in Faial (Carreira, unpublished data). The local success of *Caulerpa webbiana* in Faial Island is probably related to tolerance of local temperature ranges, fast growth rate, high re-colonization rate, and its anti-grazer toxicity (caulerpenine) (Amat *et al.*, 2008).

Between 2002, when *Caulerpa webbiana* was first seen, and 2008, the distribution of the algae significantly increased, indicating fast spread and efficient proliferation. In just a few years, *C. webbiana* expanded its boundaries from a few small patches in the outer breakwater of the harbor to over 9,900 m^2. Abundance and cover ranged from thick dominating carpets (where it first settled and in adjacent areas) to sparse variable size patches (in the limits of the local distribution). Observations and data from comprehensive surveys suggested that the alga was not only out-competing and over growing other sessile organisms, but also expanding its earlier distribution limits, in depths ranging from 5 m to 50 m. Facing the possibility of having a scenario similar to that of *Caulerpa* proliferation in the Mediterranean, the need to take action against *Caulerpa webbiana* was clear. The risk and stakes were too high to be ignored. In early 2009, a program for the active control or eradication of the *C. webbiana* population in the Azores was set in motion.

12.3 Planning the Mitigation

Developing a response to a scenario where *C. webbiana* became a threat to local organisms started in 2005, when the newly arrived alga was first clearly identified. The difficulties of eradicating exotic species, especially if one considers the additional challenge of working in the underwater environment, made it clear that an effective response with the hope of eliminating *Caulerpa webbiana* would be labor intensive, time consuming, and with a steep price. Despite the limitations, efforts and resources were allocated to the planning of a strategy and a response program.

This response program was developed to actively intervene and remove *Caulerpa webbiana* from infested areas. Even though the program was primarily focused on tackling the growth and expansion of *Caulerpa webbiana*, it was clear that researchers and scientists had to be involved in the battle. While commercial and scientific divers tested and developed different methods to remove and, if possible, terminate *Caulerpa*, biologists verified the efficiency of the methods and, with the help of volunteer divers, checked the progress of the operations and monitored the infestation and distribution of *C. webbiana* in Horta's Bay and surrounding areas. The framework of the response program reflected its focus: to **mitigate the impact of the proliferation of a newly arrived species,** with the most efficient approaches and with the lowest possible impact on local fauna and flora.

The program was divided into two major work packages, each of them with two main tasks:

Work package I – Intervention

Task 1: Technological and method development

The development and adaptation of available approaches provided technical tools and guidelines to safely remove or terminate *Caulerpa webbiana* from infested areas.

Task 2: Mitigation

Intervention and actions to remove *Caulerpa* from infested areas, making use of and applying tools and methods developed in WPI-T1. During the program, priority areas for intervention were determined based on multiple factors, including available resources, weather and maritime conditions, and the periodic assessment of the *C. webbiana* population (WPII-T2)

Work package II – Monitoring

Task 1: Efficiency and impact of techniques

Custom-designed experimentation tested the efficiency of different approaches and techniques in removing *C. webbiana* and provided a basic assessment of impacts on other organisms.

Task 2: Proliferation status of *Caulerpa webbiana*

Periodic monitoring and mapping of the presence of *Caulerpa webbiana* in infested and surrounding areas to assess the progress of mitigation actions and the local distribution and abundance of *Caulerpa* (Figure 12.2). Results were considered relevant in deciding priority areas of intervention in WPI-T2.

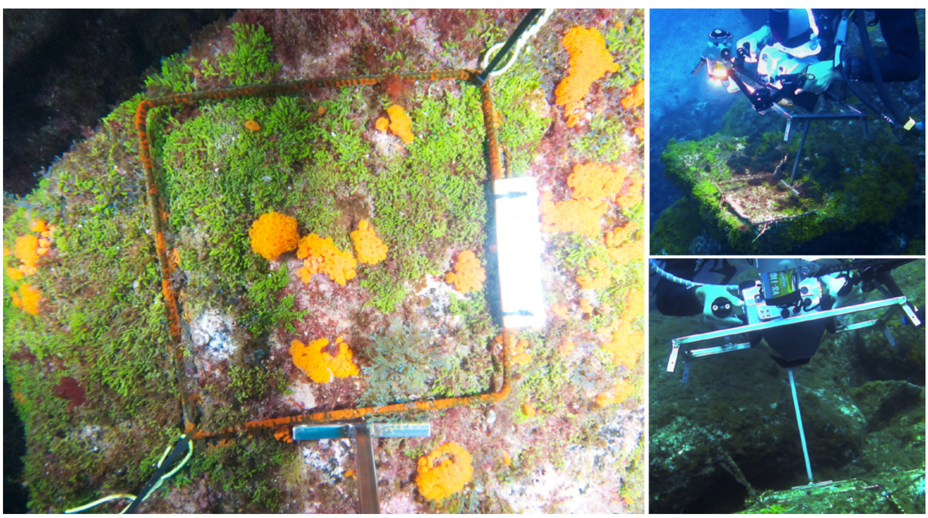

Fig. 12.2: Monitoring *Caulerpa webbiana* using 25 × 25 cm fixed photoquadrats.

Since the very early stages it became clear that it would not be possible to assure the eradication of *C. webbiana* from Faial. The assessment of *C. webbiana* distribution and abundance was crucial in determining where and when to allocate effort in removing *Caulerpa* from a given area. The speed at which *Caulerpa* was growing and spreading to surrounding areas was overwhelming, and the considerable amount of manpower and resources used in removing and terminating the alga was simply not enough.

The periodic mapping and monitoring of *Caulerpa webbiana* in areas surrounding Horta relied to a great extent on the work of volunteer divers and information provided by local stakeholders. By establishing the boundaries of *Caulerpa* and areas of exponential growth, it was possible to continuously manage the available resources and assign them to different "battle fronts": (1) inside the harbor, to avoid the spread of the algae to other islands through maritime traffic; (2) the marine protected area of Monte da Guia; and (3) areas outside previously known limits of distribution, where new reported colonies were quickly terminated in a struggle to prevent the spreading of the *Caulerpa* infestation.

12.4 Mitigating and Tech Development

The first approach to *Caulerpa webbiana* removal included the analysis of methods and principles described in relevant literature and several other empirical methods. Of these, some were later rejected and others improved. The main constraints on the application of some of the techniques, as explained in detail afterwards, were the resistance of the algae and the feasibility of the inherent operation.

Manual removal coupled with suction was the first method tested. It was rapidly rejected due to low removal rates and the extensive fragmentation and fragment dispersal that resulted.

Following the current approach to *Caulerpa* eradication used in NSW Australia (NSW, 2004), **hyaline shock** experiments were performed under laboratory conditions to test the survival rates of *Caulerpa webbiana* in concentrations ranging from 0 to 100‰. None of the tested treatments resulted in mortality of the algae after a week of exposure.

Like any other alga, *Caulerpa webbiana* depends on sunlight as its main energy source; thus, permanently preventing sunlight from reaching the alga should result in its elimination. Although preliminary tests using **smothering** showed that *C. webbiana* would not survive two weeks of light blocking, this approach proved to be unpractical in the field due to the difficulty of covering large areas of roughed high relief underwater substrates with tarp. Even worse was the difficulty of holding the tarps in place for two or more weeks due to the strong ocean agitation present throughout most of the year in the Azores. Though this method was abandoned early on, this principle was later used with a different approach (see "Sand cover").

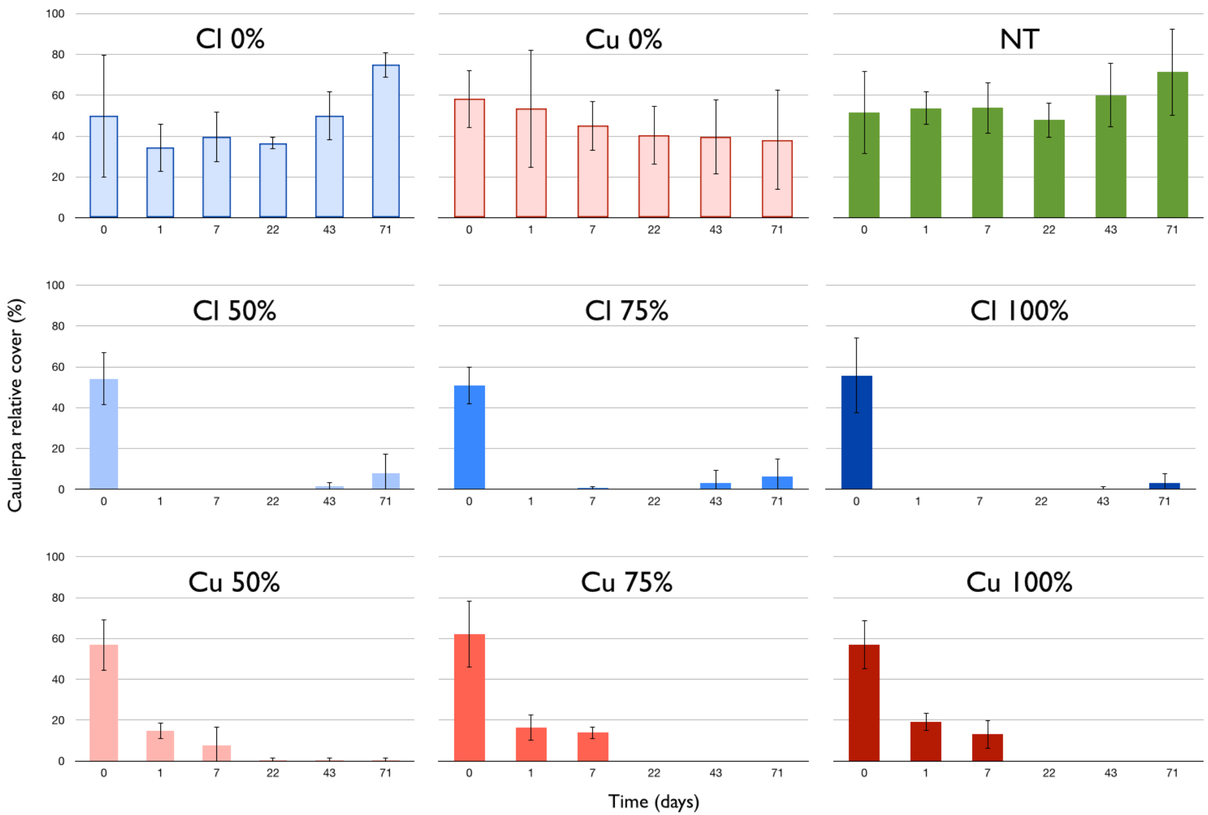

Fig. 12.6: Efficiency of CS and Chlorine treatments for long term removal (t_0 = 0 days; T_1=1 day; t_2=7 days; t_3=22 days; t_4=43 days and t_5=71 days) of *C. webbiana* at variable concentrations. Cl 0% and Cu 0% refer to control, 25%, 50% and 100% of Cl represent treatment at constant concentration (ten 50g tablets) at 2.5, 5, and 10 minutes exposure respectively. 50%, 75% and 100% Cu represent 90 g, 135 g and 180 g Cu per capsule respectively.

The rationale behind the **thermal stress** method is to expose the algae to temperature shock. Several rocks with patches of *C. webbiana* were removed from their natural locations and exposed to sea water at 68°C for approximately 10 seconds. They were immediately returned to their original location along with the control patches. After a week, and in contrast to the control patches, the treated rocks were completely free of the algae as well as any other macroalgae or invertebrates.

This experience has shown that thermal stress has the potential to be used to remove *C. webbiana* with minimal handling and reduced risk of fragmentation. Large scale application of this method would, however, require substantial technological development. Our search on commercially available technology was unable to find an applicable or adaptable off-the-shelf solution. The most important technical challenge lies in the difficulty of generating a large enough volume of warm seawater and to move it into the correct depth with low heat loss and low pressure to avoid fragmentation. To overcome these challenges, designing and producing a prototype with appropriate characteristics would be required. For this, a partnership with a commercial or technological partner would be needed and the necessary funds raised.

Like most invasive organisms, native *C. webbiana* density is controlled by herbivores that coevolved with the algae and can tolerate the anti-herbivory toxin it produces. The key concept of **biological control** includes the use of organisms that feed on the invading organism and keep its density low by controlling its biomass.

The information available indicates that there are no Azorean native organisms that could ingest significant amounts of *C. webbiana*. However, previous *in vitro* short duration experiments revealed that the sea urchin *Paracentrotus lividus* ingests *Caulerpa taxifolia* (Ganteaume *et al.*, 1998). Boudouresque *et al.* (1994) found that the alga *Caulerpa prolifera* intake is not avoided during winter-spring. With this information in mind, an experiment was designed to test if *Paracentrotus lividus* and *Sphaerechinus granularis,* naturally present in the Azores, would feed on *C. webbiana* when no other algae were available. The inclusion of *S. granularis* was due to the fact that this species has been observed in *Caulerpa*-dominated areas, and they were suspected of feeding on them. In order to test this hypothesis, sea urchins were placed in three cages (225 cm^2) and three blank cages with no sea urchins were also placed on the bottom (negative control). *Paracentrotus lividus* showed some consumption of *Caulerpa*, but preferred to scrape the substrate under the alga cover by lifting patches of *Caulerpa*. After 2-3 weeks all urchins began to die (with mortality rates up to 50%). The option of using biological control with these species of sea urchins was dismissed after this experience.

The first method selected to remove *Caulerpa webbiana* in the Azores was the CNRS (*Centre National de la Recherche Scientifique*) patented method, developed to control the expansion of *Caulerpa taxifolia* in Mediterranean marine protected areas (Uchimura *et al.*, 2000). This method is based on the lethal effect of **copper sulfide** (CS) on the Caulerpales (Uchimura *et al.*, 2000; Guillén *et al.*, 2003). This decision was supported by the promising results of pilot experiments conducted in the Azores between 2007 and 2008.

The pilot study and evaluation stage was followed by the scaling up stage. At this point it became clear that scaling up the *Caulerpa webbiana* removal using this methodology would be very difficult to achieve due to the high labor intensity involved in the cover recovery, preparation, and the divers' limited carrying capacity and high exposure to copper sulfide plumes during deployment (Figure 12.3). Other drawbacks were the difficulty of packing covers in water-tight bags containing minimal air (to be handled underwater) and the massive production of plastic waste.

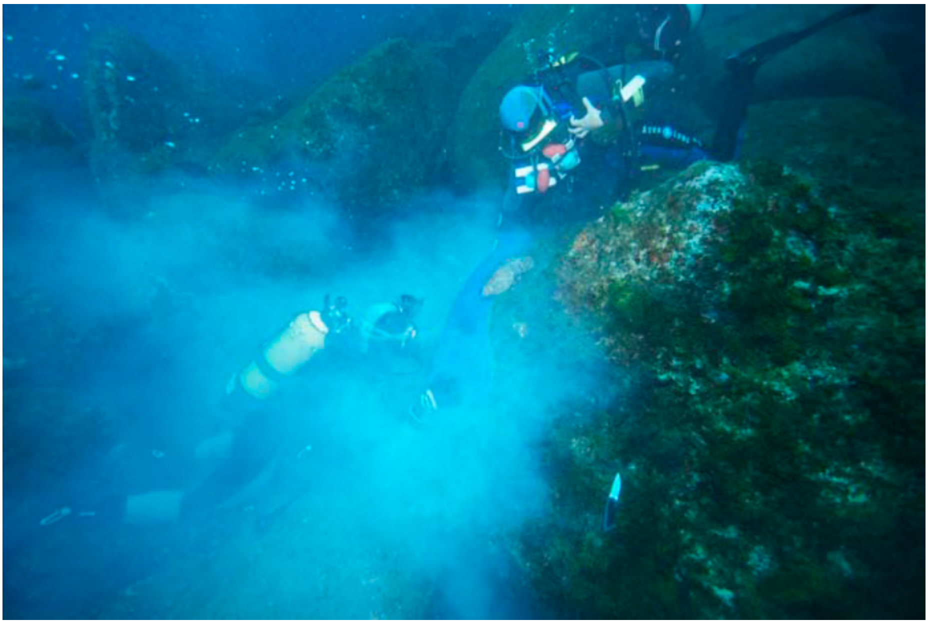

Fig. 12.3: Plume released while positioning the blanket impregnated with copper sulfate.

In order to overcome these limitations and drawbacks, multiple innovations were tested and introduced. To reduce cover preparation labor, increase diver carrying capacity, and reduce exposure to copper sulfide plumes, the copper sulfide solution was replaced with dry micronized copper sulfide contained in watertight capsules that were activated under the cover by the divers only after the cover was secured in place (with velcro). Each capsule was filled with approximately 180 g of micronized CS, and one capsule was used per square meter of cover.

Once activated, the capsules became permeable to seawater and the copper sulfide started to slowly dissolve, resulting in a CS-rich atmosphere under the tarp. After four hours, the covers could be redeployed over the next patch of *Caulerpa* or at a different site with no need for additional preparation other than repositioning a refilled set of capsules. Used capsules were collected and brought to the lab to be refilled with CS, closed, and packed in mesh bags for the next deployment. The “refills” were made from 7 cm diameter PVC pipe with 10 holes (3 mm) in both ends across its diameter, and closed on one end by a nylon lid and on the other end by a screw-on PVC lid (Figure 12.4). Two wide rubber rings (sections of reused bicycle air tube) covered the holes, making the capsules watertight. These rings were displaced by sliding them to the center section when placed under the tarp, allowing seawater to flood the capsule and slowly release CS. The covers were composed of two main materials: the upper face and the structural section is made of traction-resistant plastic tarp sewed to a geotextile (used in construction) section in the lower face. The edges of the cover were fitted with several stainless steel washers.

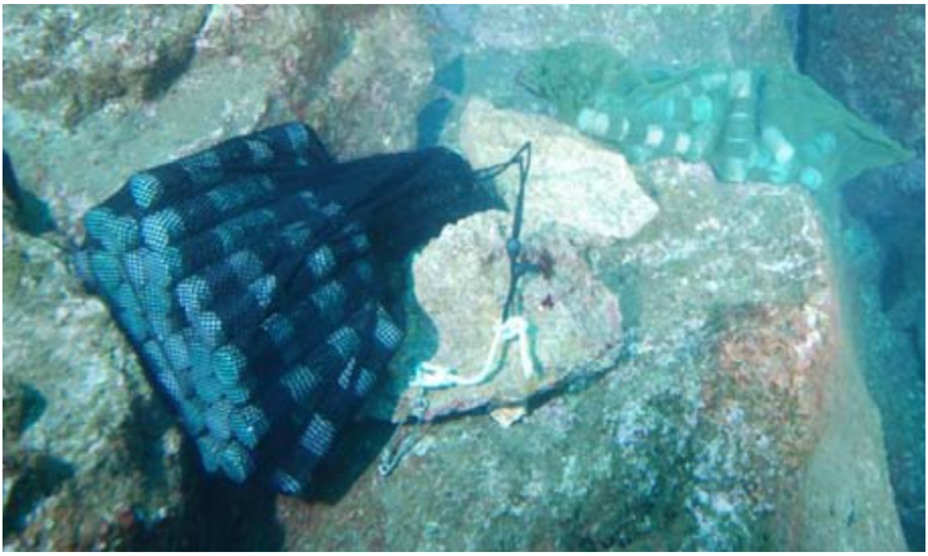

Fig. 12.4: Bags with copper sulfide “refills”.

These innovations resulted in a significant increase in productivity and greatly reduced diver exposure to CS. Diver carrying capacity increased 5 times for experienced divers, from 4 m^2/dive to 20 m^2/dive.

In addition, this method allows the manipulation of larger covers, which can be custom made depending on the characteristics of the area and size of *Caulerpa webbiana* patches. Various sizes were used, ranging from 0.5 × 0.5 m to 4 × 18 m. Simultaneously, an anchoring system was developed to effectively and quickly secure the covers to irregular, high relief rocky substrates. These elastics lines have metal hooks at the ends for easy anchoring to irregularities on the substrate, and a stretcher to adjust the elastics’ length according to the distance between anchoring points.

In soft rock areas, steel nails with rubber washers applied on reinforced eyelets along the edges were used to secure the covers. Rocks or other heavy objects could also be opportunistically used to help secure the covers.

In summary, this method significantly reduced complexity and increased productivity and safety when compared to the CNRS method. The basic steps can be summarized as follows: 1) securing tarps over the treatment area using steel nails or elastics; 2) inserting and securing activated (holes exposed) CS capsules under the covers using the velcro attachments; 3) after 4 or more hours, recovering empty capsules and moveing covers to the next area; 4) securing the covers over untreated patches and placing refilled CS capsules. This procedure can be repeated indefinitely in large, heavily infested areas, reusing covers with no need to surface for cover preparation between deployments. Preparation between deployments is essentially limited to refilling capsules with CS.

Although the CS cover method was very effective for large infested areas and large isolated patches, this was not the case for dispersed small patches in unmapped areas. To deal with small and dispersed patches of CW a precision removal method was developed based on the California *Caulerpa* eradication experience. In the California case study, **chlorine** was used with success as a lethal agent and primary eradication method by covering large areas colonized by the algae and pumping in chlorine from land reservoirs (Williams & Schroeder, 2004).

After testing the lethal effect of chlorine on *Caulerpa webbiana*, it was concluded that it could be efficiently used as lethal agent. Based on this, an apparatus capable of delivering a controlled and localized stream of chlorine-saturated seawater to small patches was developed and used extensively (Figure 12.5). The apparatus, a chlorine pump, consisted of a pressurized container where solid chlorine tablets (ten 50 g tablets) were added to seawater. The chlorine tablets dissolve gradually in sea water resulting in hypochlorite. The flow of chlorine was controlled by the diver and the controlled flow was applied one centimeter above the patch, spaying the desired area until the alga started to bleach. The pressurized chlorine reservoir allowed a constant flow of chlorine at any depth without effort. The pressurization was obtained by connecting a 4 liter SCUBA tank with compressed air (up to 200 bar). The air pressure was reduced in two stages. First, a SCUBA first stage diving regulator reduced pressure to 9 bar, then a second pressure gauge (used in industrial butane gas facilities) further reduced the pressure to the final 3 bar. Additionally, there was a stopcock to prevent the entry of chlorine in the compressed air system when depressurized.

The chlorine reservoir could be recharged during the dive as many times as necessary by closing the air inlet, opening the reservoir and allowing seawater in and air out. Additional chlorine tablets could be added when previous tablets had lost 80% of their initial volume. Additional tablets were carried in 50 cm long PVC capsules with PVC screw caps on both ends. The continued use of these devices, in combination with the corrosive characteristics and oxidative chlorine from sea water, requires regular inspection and maintenance.

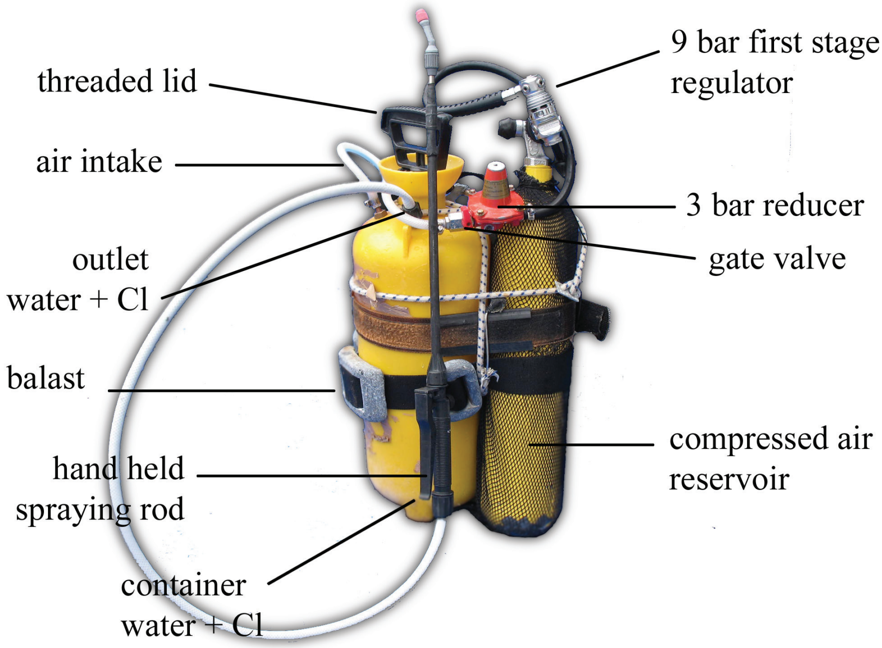

Fig. 12.5: Chlorine pump schematic.

Due to the toxic and corrosive characteristics of chlorine and the increased risk of exposure to this chemical, it is necessary to provide divers with adequate means of protection. The use of full body wet or dry suits, gloves, and full face masks reduces exposed area and protects divers from rashes. Likewise, it is also necessary to use adequate protection when moving, preparing, and servicing chlorine pumps and related equipment in air. For **safety** reasons, the handling of chlorine and chlorine equipment requires the use of gloves, a full body impermeable suit, and a full face mask with specific filtration for chlorine compounds.

With the continued use, the seals in the system, particularly on the reservoir lids, may allow some chlorine gas to escape during transport. This issue may be tackled with the use of a more robust and pressure-resistant container (aluminum or Plexiglas, for example).

Efficiency of different concentrations of both CS and Chlorine were tested in order to determine the lowest possible concentration that still produced lethal effects (Figure 12.6). These experiments led to a 50% reduction of the initial amount of CS used per cover area while still achieving lethal effects. The initial concentration was equivalent to the amount of CS used in the solution necessary to spray a given area of cover with the CNRS method.

The use of **sediment** (mostly marine sand from dredging) to smother *Caulerpa webbiana* over large infested areas was also tested as a potential method. The idea was based on the simple principle that, like any alga, *Caulerpa* requires light to survive. The concept is to simply cover large areas infested with *C. webbiana* with sand and other aggregates, blocking the sunlight until it dies. This method was effective in removing *Caulerpa* over large areas using cheap dredged sand.

Approximately 3,920 m^3 of sand were deposited in an area of 3,000 m^2. A visual assessment of the site before, immediately after, and four weeks after the deposition of sand showed that the method effectively eliminated *C. webbiana* from low relief areas, but was not equally efficient in high relief areas, because the sand did not cover boulder tops. High relief areas require greater amounts of sand delivered per unit area. The abrasion caused by the settling of dropped sand does not appear to cause significant fragmentation of the seaweed (although this risk must be considered).

In summary, this method is potentially useful if the following conditions are met: i) sheltered area; ii) flat areas; iii) densely colonized by the alga.

12.5 Public Involvement

There was an effort to inform the general public about alien species and, in particular, about the *Caulerpa webbiana* issue. The main objectives were:
- Emphasize early detection of newly invaded areas or the arrival of new alien species;
- Inform about the different tasks that were being carried out, thus also justifying the financial effort;
- Raise awareness about marine environmental problems.

Posters, placards, public sessions, and a webpage were produced over the years. In order to disseminate the objectives and results, there was also an effort to communicate at an international level.

Multiple versions of posters advertising the problem of invasive species were developed, always trying to be as precise, objective and engaging as possible. Distribution started with the beginning of the bathing season, taking advantage of a larger target population and greater public attention to this topic in order to maximize the outreach and its usefulness. Posters were also affixed in various public places such as cafes, clubs, etc. Enterprises and associations related to underwater activities and local communities were also used as communication and distribution vectors, using posters and graphic information.

Placards were placed near SCUBA diving and whale watching enterprises. Dive center receptions held informal public awareness sessions addressed mainly to employees and included the distribution of advertising material. Sessions were held on several islands of the Azores.

Drawing on the potential for dissemination through the Internet, a webpage was created and some videos of the species and the work carried out were shared. All content was made open access. The website was created at www.caulerpawebbiana.com to facilitate the communication of observations of *C. webbiana* to the community. The information was updated with news and images that gave an account of the developments, major events, and progress of eradication efforts. The messages sent to the site were automatically directed to the coordinator of the project in order to optimize the speed of response. Despite the fact that the priority was to monitor, explore, and test new eradication methods and eradicate the algae, effort was still made to ensure the website was regularly updated.

The team involved in the eradication activities participated in the World Conference of Marine Biovdiversity 2011 that took place in Aberdeen. The 5-minute video shown during this event summarized the objectives, methods, and results achieved so far. Material was also provided for a documentary produced for “Sentinelles de la Nature”, featuring Cecille Favier and Aymeric Alardet and produced by the Films Concept Associés series.

12.6 Fighting *Caulerpa webbiana*

After the first few months of intervention to eradicate the green algae *Caulerpa webbiana*, the boundaries of distribution, both North and South, had been substantially retracted. In the South, the decrease was due almost exclusively to the intensive action of the intervention team, which focused its activity on this front. In the North, the retreat of the invasive algae was due to natural causes, probably a combination of relatively low temperatures (14–15°C) and the severe and persistent wave propagation caused by the particularly harsh winter. Probably for the same reason, there was a very significant reduction in the biomass of *C. webbiana* on the North coast.

During winter, when the weather and sea conditions make it impossible to work in more exposed areas, the team focused its efforts on the dock. The effort put into eradicating the invasive *Caulerpa webbiana* inside the port of Horta resulted in a drastic reduction of the percentage coverage in higher density areas, which included the docking area of deeper draft vessels (potential vectors for dispersion). Contrary to initial expectations, even in relatively protected locations, the strong sea waves that were felt during the entire winter and early spring prevented any mission to eradicate off port. It was not possible to resume eradication efforts in the outer areas until the beginning of April.

After the improvement of weather conditions in the spring, the work was concentrated in the outer areas. During the four summer months, the work was, in general, fruitful.

An important portion of the infected area was located on a slope ranging from 30 to 43 meters deep. There, the progression and treatment of work has been very slow.

Areas previously treated were recolonized and the biomass of *C. webbiana* has increased again. There were portions treated three consecutive times since, and after each passage of time, new small colonies, more difficult to locate, have emerged. In just two weeks after the application of treatments, it was possible to find new colonies with coverage of about 20–30 cm^2. The alga has demonstrated its great vitality by resettling in only a few months in areas where it had been naturally eliminated during the winter period.

Due to this process of reappearance and recolonization (see Figure 12.7), and in accordance with the strategy and priorities established at the beginning of the control and eradication program, efforts and available resources were focused on the survey and eradication of new colonies that appeared in the extreme of the distribution range. By the end of 2010 it was possible to eliminate all new colonies identified, pushing the distribution to the previous year's limits.

Some volunteer work was used, especially in the actions concerning the detection of new colonies. The objective of the exploratory missions was to inspect vast areas within the limit of distribution and beyond, and in areas of intervention from the previous year. Colonies of *Caulerpa* were marked and mapped for future treatment.

Missions had to be meticulously planned because of the size of the zone, the irregular bottom (homogenous, with only a few elements useful for orientation), and dispersed colonies of *Caulerpa*. In these areas, mobile guide lines were placed to create "corridors" that divers inspected. The 100 m lines were placed perpendicular to the depth gradient and, as the "corridors" were inspected and treated, the mark lines were transferred from deeper to shallower zones. This method, although time consuming, proved to be effective.

Sand was tested as a smother control method for *Caulerpa* during the summer of 2011. The method has limitations, especially in sloppy areas. Although it is effective when it fully and permanently covers *Caulerpa* colonies in flat bottoms, colonies covering large blocks survived in the test zone.

After this experiment, by the end of 2012, 137,000 m^3 of sand was used to cover an area of 30,000 m^2 that was highly contaminated with *Caulerpa webbiana*. As expected, the alga disappeared in the covered area. As it represented an important part of the total area, the contamination was greatly reduced. The impact on the community was very high; nevertheless, the overall outcome was positive.

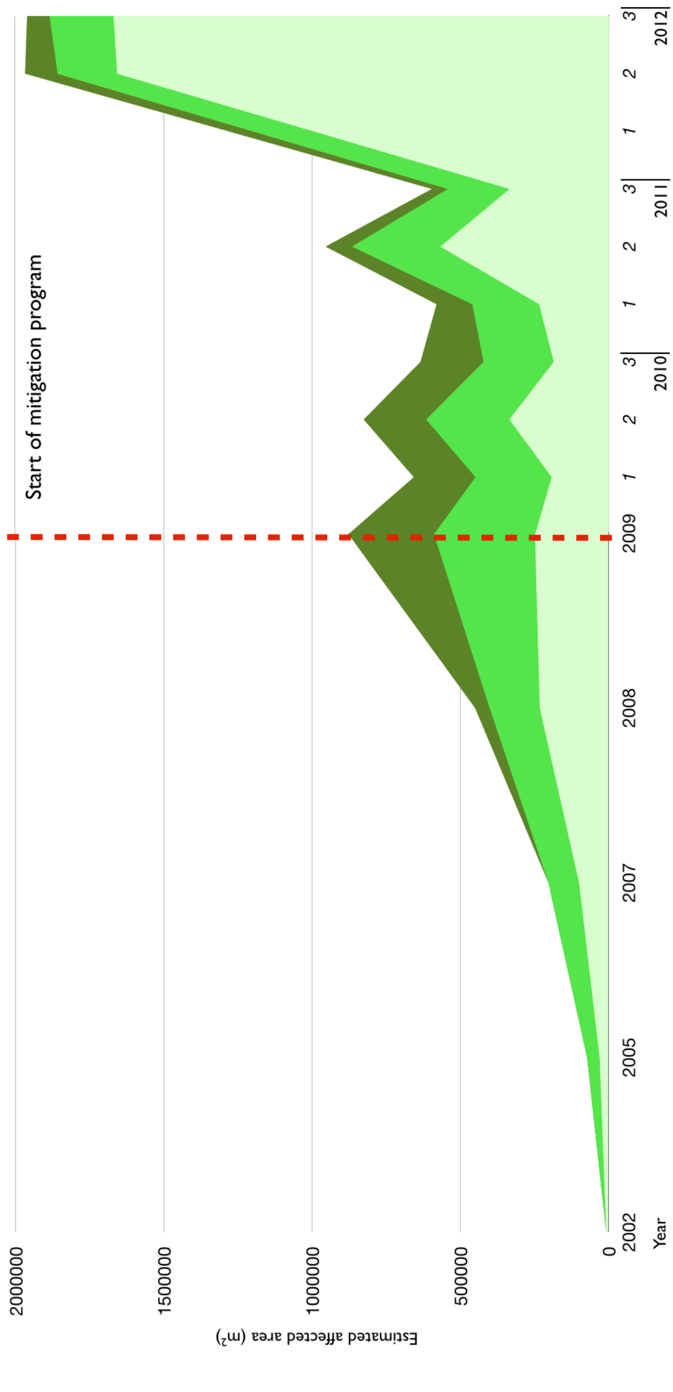

Fig. 12.7: Variation of *Caulerpa webbiana* abundance in Faial over time. In the first months of 2011 there was intervention against the alga. In 2012, the decision to cover the alga with sand was made (light green represents low density areas, medium green stands for medium density areas and dark green represents high concentration areas.

12.7 Lessons Learned

According to Amat *et al.* (2008), the green algae *Caulerpa webbiana* presents no invasive characteristics in other places where it occurs (eg. Madeira and the Canary Islands). There is probably a natural control factor in these other locales, such as predation, that is absent in the Azores. Without human intervention, the expansion and increase in coverage of infested areas of the Azores could achieve disastrous proportions (Figure 12.8, 12.9).

This program was started in order to control and, if possible, eradicate *C. webbiana* in the Bay of Horta and surrounding areas. As shown, the growth rate, resistance, toxin production, and vegetative reproduction dramatically enhance the expansion of the distribution of this alga, making complete eradication effectively impossible.

As observed in the Canary Islands (Haroun *et al.*, 1984), this seaweed has a seasonal growth cycle and is more vulnerable in winter and more resistant during the summer time — this is also true in the Azores. This seasonal cycle has a clear impact on its capacity for expansion and growth, with obvious increases at the height of spring and summer.

The aim of eradicating the algae became increasingly difficult, and to control its growth demands continuous action and high human and material resources. Throughout the initial phase of the program, it was found that, with the available means and techniques, control of *C. webbiana* on Faial Island was beyond reach. After introducing several technical improvements, the program was successful in mitigating and containing this invasive alga in the vicinity of the Bay of Horta.

In 2012, several tons of sand were placed over the densest area of *Caulerpa webbiana*. This action, combined with the previous actions that had constrained the green algae to the limits of the surroundings of Horta bay and, probably, the low water temperatures registered in the winter of 2012/2013, was crucial to the substantial reduction of this local population.

This program was crucial to limit the expansion of *Caulerpa webbiana* on Faial Island. From this perspective, despite the failure to eradicate the algae within the Bay of Horta, the program played a key role in mitigating the problem and in helping the preservation of local biodiversity and biotopes, as well as in controlling the expansion of the area affected by this proliferating algae.

If the program is to continue, especially if the pattern of recolonization continued, it would be mandatory to verify if there was any contamination or accumulation of chlorine or copper along the trophic chain or substrate, and if the permanent use of these chemicals would influence the condition and ecological succession of biotopes. The methods used were those showing the best results and proved most suitable for the eradication and control of *Caulerpa*, but the toxicity and pollutant nature of chlorine and copper sulfide should not be neglected.

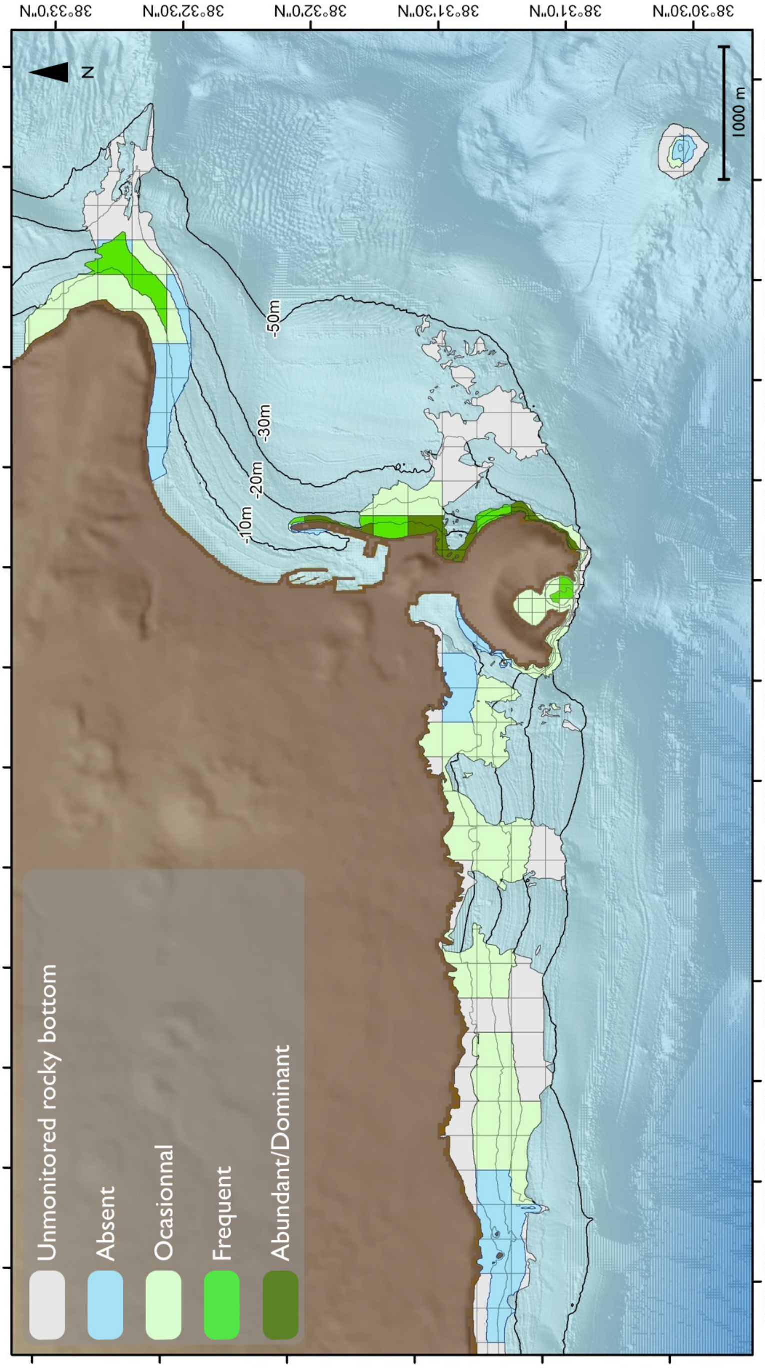

Fig. 12.8: Southeast Faial Island and *Caulerpa webbiana* invasion maximum.

Fig. 12.9: *Caulerpa webbiana* expanding.

Working in the marine environment, the rate of growth and recovery of the alga, the limited work possible during winter time, and the lack of appropriate technologies were obvious constraints to the control and eradication of *Caulperpa webbiana* in Faial. Nevertheless, the greatest handicap this program faced was lack of resources. The availability of more resources would have eliminated these limitations and would have enabled the appropriate response to the scale of the problem.

It is important to note that in similar cases of proliferation and invasion by algae of the genus *Caulerpa*, almost all similar initiatives were less successful in controlling the growth of proliferating algae than this program. There are two exceptions: the case of *Caulerpa taxifolia* introduction in Agua Hedionda Lagoon (California), and in Huntington Harbor, Los Angeles (California), in the late 1980s.

The program has implemented operational improvements in order to adjust and adapt to the existing resources and has developed new methods and techniques that tackled the needs, conditions, and fulfilled the main mitigation objectives. It must be understood that a mitigation plan is not intended to eliminate *Caulerpa* and that the problem will persist. Therefore, such a program should be viewed as an approach that should be maintained continuously.

Their toxicity as pollutants and the other unhealthy characteristics of the chemicals used as algaecides point towards the need for research and technological development of effective alternative methods. This should be considered a priority. Thus, it is recommend that support be given to a project, parallel to and independent of other initiatives, solely focused on the research and development of new approaches and tools to combat biological invasions.

Based on the experience gained during the program, it is possible to compile general high level recommendations to define the strategy and future plans of action against species that constitute a threat to biodiversity and local biotopes with associated environmental, ecological, or socio-economic consequences:

a) Invest in early warning;
b) Discard non-intervention;
c) Do not ignore the risks associated with the proliferation of exotic species;
d) Consider the response and treat bioinvasions as a priority;
e) Adapt the existing means and available resources while creating and implementing an operational plan for eradication.

Morphology, weather conditions (including ocean dynamics), remoteness, and isolation are extreme in the Azores. This means that the strategies employed and lessons learned in this archipelago are, most probably, effective elsewhere. In particular, the high level considerations stated earlier should be used regardless of geography or ecosystem.

12.8 Next Steps

Fortune has played a major role in this matter. The availability of sand and the extreme winter weather between 2012 and 2013 were fundamental to the observed decrease in *Caulerpa webbiana*.

The future must necessarily include a continued monitoring plan and action must be taken to actively control invasive species. These are things repeatedly mentioned by scientists (Micael *et al.*, 2014).

As in many places around the world, and partially as a result of the delay in taking action against *Caulerpa webbiana*, decision makers in the Azores are presently taking invasive species seriously. Recommendations, such as the ones offered by Ojaveer *et al.* (2014), are adapted here and should be followed in the Azores, including:

- The Regional Government should have staff with understanding of marine invasion processes. This is valuable and should be maintained;
- Outsourcing and hiring experts and consultants whenever needed;
- Guidelines to deal with NIS should be developed involving decision makers, local authorities, scientists, and stakeholders. Early detection and monitoring should be one of the main targets of these guidelines, which will promote standardized

approaches for data collection, compilation, and information systems, to allow fast response and action when dealing with new NIS;
- Among the usual vectors that promote the entrance of NIS, only vessels and ships seem to be particularly important in the Azores. Nevertheless, the movement of live bait for tuna fisheries might be responsible for the entrance of *Diplodus vulgaris* in the Azores (Afonso *et al.*, 2013). Those should be particularly carefully inspected;
- The work carried out in the Azores, despite being chosen by the scientific community and available funding for research, covers the use of the three indicators expressed in the Commission Decision 2010/477/EU. Namely, (1) there is an initiative for the surveillance of marine alien species; (2) accurate species lists for fish, macroalgae and mollusks are being created; and (3) there is an effort dedicated to detaining invasive species, as was the case with the *Caulerpa webbiana*. Continuous support should be given to this work;
- In the Azores, all the typical and foreseen vectors for marine species introductions are occasionally studied by marine ecology, marine biology, and fisheries-related research (Cardigos *et al.*, 2006; Afonso *et al.*, 2013; Cardigos *et al.*, 2013; Micael *et al.*, 2014, among others). This includes ballast water analysis, boat hull incrustation identification, biogeographic studies, and others. A large-scale monitoring program was proposed, but is not yet funded;
- There is a movement in the Regional Government of the Azores to grant all the authority over maritime matters to only one regional directorate. These efforts are being made to centralize information and decision making processes concerning marine and maritime matters, which will provide better response times when dealing with NIS and marine invasion threats. This effort should be kept and reinforced.

12.9 Acknowledgements

Jaen Nieto Amat was a consultant in the development of the *Caulerpa webbiana* eradication program of the Azores and we are grateful for her assistance and for the work she produced. We respectfully acknowledge the support and commitment provided by all the professional and voluntary divers that have helped implement the “brigade anti-*Caulerpa*” monitoring program and helped fight this invasive alga on Faial island. Emanuel Arand and *Imag*DOP/UAz developed Figure 12.5. All photos are from the *Imag*DOP/UAz photo image bank. We thank the Harbour of Horta administration and collaborators, including the President, Eng. Fernando Nascimento, and Eng. António João.

In a nutshell

- The fight against *Caulerpa webbiana* started in 2008 in the Azores.
- If awareness and proper reaction methods were in place, the fight could have started several years earlier.
- Even with a huge effort, it now seems too late to eradicate the new population. This alga will likely remain on Faial Island, and the resultant ecological damage is significant.
- Only control actions preventing spreading to surrounding areas, seems feasible.
- This calls for an increase in awareness, in the implementation of early warning and rapid response, and in financial commitment to fight marine invasions.
- Fighting against *Caulerpa webbiana* can be done efficiently using different methods according to the specific context (localization and density, mainly) as discussed in this chapter.

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