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Effectiveness of the California State Ban on the Sale of *Caulerpa* Species in Aquarium Retail Stores in Southern California

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Abstract The invasion of the aquarium strain of the green alga *Caulerpa taxifolia* and subsequent alteration of community structure in the Mediterranean Sea raised awareness of the potential for non-native seaweeds to impact coastal communities. An introduction of *C. taxifolia* in southern California in 2000, presumably from the release of aquarium specimens, cost ~$7 million for eradication efforts. Besides *C. taxifolia*, other *Caulerpa* species being sold for aquarium use also may have the potential to invade southern Californian and U.S. waters. Surveys of the availability of *Caulerpa* species in southern California aquarium retail stores in 2000–2001 revealed that 26 of 50 stores sold at least one *Caulerpa* species (52 %) with seven stores selling *C. taxifolia*. In late 2001, California imposed a ban on the importation, sale, or possession of nine *Caulerpa* species; the City of San Diego expanded these regulations to include the entire genus. To determine the effectiveness of the California ban, we resurveyed *Caulerpa* availability at 43 of the 50 previously sampled retail stores in southern California in ~2006, ~4 years following the ban. Of the 43 stores, 23 sold *Caulerpa* (53 %) with four stores selling *C. taxifolia*. A χ^2 test of frequency of availability before and after the California ban suggests that the ban has not been effective and that the aquarium trade continues to represent a potential vector for distributing *Caulerpa* specimens, including *C. taxifolia*. This study underscores the need for increased enforcement and outreach programs to increase awareness among the aquarium industry and aquarium hobbyists.

Keywords *Caulerpa* · Invasive species control · Management · Regulation effectiveness · Aquarium industry

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Introduction

Environmental management attempts to conserve resources and protect wildlife, either at the species or ecosystem level, through regulations that control human impacts. By regulating interactions between people and the environment, management emphasizes species conservation and the maintenance of healthy ecosystem functions and processes (Szaro and others 1998). For example, at the species level, international treaties developed over the past decades have placed limitations on commercial whaling, tuna, and billfish operations in attempts to protect individual stocks (Gambell 1993; Allen 2010; nmfs.noaa.gov). At the ecosystem level, U.S. national and state parks and marine reserves are designated to protect natural resources and biodiversity through habitat conservation. While some management practices are effective in their goal of protecting wildlife, such as the success of no-take marine protected areas (MPAs) (Halpern 2003), other strategies

have been unsuccessful. For example, despite numerous regulations designed to prevent illegal wildlife trafficking in the United States, seizures conducted by U.S. Fish and Wildlife Service authorities are believed to represent only a small fraction of actual violations (McMurray 2009). While species or ecosystem management strategies are, for the most part, based on sound scientific knowledge, it is imperative that the value of regulations is rigorously tested to determine their efficacy (Hockings and others 2006).

Introductions of non-native species threaten global biodiversity and ecosystem functioning (Ruiz and others 1997, 2000; Wilcove and others 1998; Bax and others 2001) and can result in severe economic costs (Pimentel and others 2000; McNeely 2005). Consequently, invasive management actions to deter the introduction have received considerable attention in North America, Europe, and Australia. Numerous international and U.S. federal and state regulations have been enacted to control the transport of non-native species. In the U.S., federal regulations focusing on non-native species include the Lacey Act, the Federal Noxious Weed Act, the Plant Protection Act, and others, while a mixture of regulations are set at the individual state level. If a non-native species becomes established, several management plans exist to respond to these introductions, including environmental education and outreach, eradication, and control efforts to stop further spread. These include federal and state policies and regulations that manage at the species level, such as the U.S. Brown Tree Snake Control and Eradication Act or the California Department of Fish and Game Code (6048–6049) for *Hydrilla*, and at the ecosystem level, such as the U.S. Public Lands Corps Healthy Forests Restoration Act or the Washington State Forests and Forest Products legislation (Code 76).

Management practices addressing the introduction and spread of non-native species in terrestrial systems are well established with particular attention paid to agricultural pest management because of the large economic impacts to the industry. However, economic and environmental damage caused by aquatic invasive species is also of great concern. Aquatic non-native species management strategies in the U.S. at the federal level include, among many others, the U.S. Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990, the National Invasive Species Act of 1996, and the U.S. Great Lakes Fish and Wildlife Restoration Act of 2006; a myriad of regulations are also set at the state level (e.g., Oregon Aquatic Nuisance Program). These strategies place emphasis on regulating the transport of aquatic non-native species through vectors such as ballast water, ship-hull fouling, aquaculture facilities, fish and shellfish importation, and the aquarium trade (Carlton 2001; Hare and Whitfield 2003). For example, one of the many regulations in the U.S. Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990, expanded into the National Invasive Species Act of 1996, requires that ships entering the Great Lakes release their ballast water in open water prior to arrival as an attempt to control the introduction of zebra mussels and numerous other non-native species. Ballast water exchange requirements were later expanded to include all vessels arriving at any U.S. port by the U.S. Coast Guard (USCG Mandatory Ballast Water Management Program for U.S. Waters 2004), with multiple state regulations also in effect.

The importance of the aquarium trade as a potential vector for aquatic non-native species has been historically recognized in North America (Courtenay and Stauffer 1990; Fuller and others 1999; Whitfield and others 2002), Europe (Verlaque and Fritayre 1994; Harlioglu and Harlioglu 2006), and Asia (Hayes and others 2008). Ornamental species can be introduced into non-native habitats either intentional or unintentionally, but is often attributed to release of unwanted aquarium pets into local waterways. A majority of examples of non-indigenous species introduced through the aquarium trade are from freshwater systems; for example, Fuller and others (1999) documented 126 non-native freshwater fish species in U.S. waters with 42 species being established. Recently, the aquarium trade as a vector for introduced marine species has received much attention (Eldredge and Carlton 2002; Whitfield and others 2002; Ribera Siguan 2003; Padilla and Williams 2004; Semmens and others 2004; Walters and others 2006; Murray and others 2007), although attributing the aquarium trade as the true vector has been elusive. For example, introduction of the Indo-Pacific lionfish *Pterois volitans* along the East Coast of North America was most likely due to accidental or deliberate release from aquaria (Whitfield and others 2002; Hare and Whitfield 2003). The aquarium trade also is thought to be the vector responsible for the successful invasion of three marine invertebrate species on the Hawaiian Islands (Eldredge and Carlton 2002). Introductions of invasive seaweeds through the release of aquarium-traded specimens have also occurred, resulting, in some cases, in large ecological and economic impacts. Best known is the release of the invasive aquarium strain of the green alga *Caulerpa taxifolia* into the Mediterranean Sea in 1984 (Meinesz and Hesse 1991). Subsequent to its introduction, this seaweed spread across much of the Mediterranean coast by 2000 (Meinesz and others 2001), resulting in widespread impacts on biodiversity (e.g., Verlaque and Fritayre 1994; de Villèle and Verlaque 1995; Ceccherelli and Cinelli 1997; Levi and Francour 2004). Following the Mediterranean Sea invasion, the aquarium strain of *C. taxifolia* invaded Australian (Schaffelke and others 2002) and southern California waters (Jousson and others 2000) in 2000; California introductions resulted in the expenditure of over $7.7 million U.S. dollars for an apparently successful eradication effort (Merkel and Associates, Inc. 2006). Besides *C. taxifolia*, other *Caulerpa*

species, such as various *C. racemosa* subspecies, *C. scalpelliformis*, *C. brachypus*, and *C. filiformis,* have invaded numerous locations, including the Mediterranean Sea, Australia, and Canary Islands (Davis and others 1997; Verlaque and others 2003, 2004; Jacoby and others 2004; Ruitton and others 2005; Cummings and Williamson 2008); the vectors for these introductions are unclear.

To reduce the likelihood of an invasion similar to the Mediterranean Sea, the aquarium strain of *C. taxifolia* was placed on the Federal Noxious Weed List in 1999 making it illegal to import this species into the U.S. or transport it across state lines. Recognizing that the aquarium trade was a potential vector for spreading invasive *Caulerpa* spp., researchers conducted surveys of *Caulerpa* availability online nationwide (Walters and others 2006) and in retail stores in southern California (Zaleski and Murray 2006). Online surveys and purchases revealed that the genus was readily available nationally, although the aquarium strain of *C. taxifolia* was never found (Walters and others 2006). In southern California, Zaleski and Murray (2006) found that 26 of 50 aquarium retail stores surveyed in 2000–2001 sold at least one species of *Caulerpa*, and seven sold specimens of the wild strain of *C. taxifolia*. Following its introduction in southern California, California imposed a statewide ban in late 2001 (DFG Code 2300) on the importation, sale, and possession of *C. taxifolia*, plus nine other *Caulerpa* species either thought to be potentially invasive or easily confused with *C. taxifolia*. The City of San Diego, a nearby city where the 2000 *Caulerpa* invasion occurred, expanded the ban to include the entire genus (Ordinance no. 18967).

Despite the California state ban on the possession and sale of potentially invasive *Caulerpa* species, the efficacy of the regulatory policy has never been evaluated. The previous study by Zaleski and Murray (2006) documenting the availability of *Caulerpa* in aquarium retail stores conducted prior to the ban offers a rare opportunity to investigate the actual response to this legislative management tool. Herein, we examine the effectiveness of the California state ban on the sale of *Caulerpa* species in southern California aquarium retail stores by revisiting the same set of stores originally sampled by Zaleski and Murray (2006) to determine post-ban availability. If the ban has been successful, few or no specimens of the banned *Caulerpa* species should be available for sale in these southern California retail outlets.

Methods

Store Selection

Zaleski and Murray (2006) visited 50 southern California aquarium retail stores in 2000–2001, selected randomly from the three major counties (San Diego, Orange, and Los Angeles) in the region. These surveys focused on independent, non-franchised stores that specialize in ornamental aquariums for hobbyists. Large corporate/franchise pet stores were not included based on preliminary visits that revealed that seaweeds were never found for sale in these retail outlets. From December 2005 to January 2007, we revisited 43 of the same aquarium stores originally sampled by Zaleski and Murray (2006) to determine the availability of *Caulerpa* species ~4 years following the California state ban. Seven of the stores sampled previously were no longer in business, therefore, could not be resurveyed. This subsample of re-surveyed stores included 9 in San Diego County, 16 in Los Angeles County, and 18 in Orange County.

Stores were visited once to determine the availability of *Caulerpa* species for sale and in stock. Upon entering each store, tanks and refugia were visually scanned for the presence of *Caulerpa*. Available *Caulerpa* species were purchased and later identified in the laboratory. Although *Caulerpa* species can be difficult to identify based on morphological characteristics, particularly to the untrained, the authors (Smith, Murray, and, in particular, Zaleski) have experience working with these seaweeds and we are confident in our identifications. Species that were present in aquaria but not available for sale were identified on site and recorded. Purchased *Caulerpa* specimens were preserved as herbarium specimens using standard preparatory procedures (e.g., Abbott and Hollenberg 1976). We calculated the frequency of occurrence of each species for each county and compared results with findings of Zaleski and Murray (2006). Differences in proportions between stores selling *Caulerpa* taxa before and after the ban were analyzed using a χ^2 test.

Results

2005–2007 Availability

Of the 43 stores surveyed, 23 locations (53 %) sold *Caulerpa* (Table 1) with six stores found to sell more than one species. A total of 34 specimens of *Caulerpa* taxa were purchased at the 23 locations where *Caulerpa* was being sold. For those stores selling *Caulerpa*, a mean of 1.5 species were available per store. *Caulerpa* species were sold at a higher frequency in Los Angeles County (75 % of visited stores), followed by Orange County (50 %) and San Diego County (22 %) (Fig. 1). In addition to the stores offering specimens for sale, three stores had one or more species of *Caulerpa* in stock but not available for purchase. An additional three stores sold at least one species of *Caulerpa* but would not sell other species in stock; in most of these cases, specimens were not sold due to low stock

Table 1 The number of stores selling *Caulerpa* species in San Diego, Orange, and Los Angeles counties in southern California during 2005–2006 surveys (n = number of stores visited)

Banned species (italic)	County			All counties	
	San Diego ($n = 9$)	Orange ($n = 18$)	Los Angeles ($n = 16$)	Total ($n = 43$)	% of stores re-surveyed
Any *Caulerpa* species	2	9	12	23	53.5
C. racemosa *	0	1	5	6	14.0
C. sertularioides *	1	4	0	5	11.6
C. racemosa v. peltata *	0	3	1	4	9.3
C. serrulata v. hummii	0	2	2	4	9.3
C. taxifolia *	0	1	3	4	9.3
C. microphysa	1	1	1	3	7.0
C.racemosa v. lamourouxii *	0	2	0	2	4.7
C. prolifera	0	0	2	2	4.7
C. brachypus	0	2	0	2	4.7
C. serrulata	0	1	0	1	2.3
C. sp. unidentified	0	0	1	1	2.3

Indicated is the percentage of 43 stores that these species were purchased from. The species currently on the banned list are demarcated with an asterisk

rather than knowledge of the law or those species being on the banned list.

A total of eight species and 10 taxa of *Caulerpa* were purchased and identified (Table 1); the identity of one specimen could not be determined with confidence. Of the most commonly sold *Caulerpa* species, 4 of the top 5 were from the banned list (Table 1), including *C. racemosa* (14 % of visited stores), *C. sertularioides* (11.6 %), *C. racemosa* v. *peltata* (9.3 %), and *C. taxifolia* (9.3 %). The four purchased *C. taxifolia* specimens were not believed to be the invasive aquarium strain based on morphological characteristics as the aquarium strain is markedly larger and more robust; the purchased samples were neither large nor robust.

Effectiveness of California Ban

Availability of *Caulerpa* spp. in retail aquarium stores was similar for pre-ban surveys in 2000–2001 and post-ban surveys in 2005–2007 ($\chi^2 = 0.021$, $df = 1$, $P = 0.886$) with approximately half of the stores sampled selling at least one species in both studies (Fig. 1). Despite a similar frequency of availability, the number of species available in those stores selling *Caulerpa* decreased from 2.4 species per store in 2000–2001 to 1.5 in 2005–2007. We also found that not all of the same aquarium stores were selling *Caulerpa* during both survey periods with 8 stores selling in 2000–2001 but not in 2005–2007 and 6 stores selling in 2005–2007 but not in previous surveys. Among the 3 counties, a large, but not significant, decrease in the availability of *Caulerpa* was found in San Diego County (55–22 %; $\chi^2 = 2.216$, $df = 1$, $P = 0.142$) over the two sampling periods with a minor decrease in availability in Orange County (60–50 %; $\chi^2 = 0.383$, $df = 1$, $P = 0.535$) (Fig. 1). In contrast, a large significant increase in availability was observed in Los Angeles County (42–75 %; $\chi^2 = 3.838$, $df = 1$, $P = 0.005$).

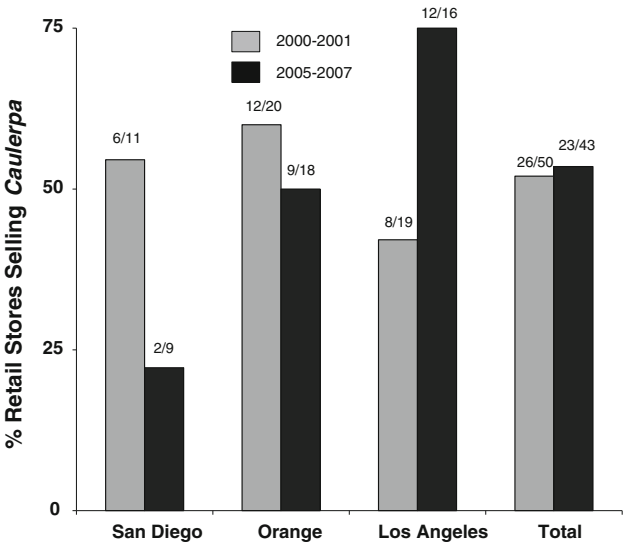

Fig. 1 Percentage of retail stores selling at least one species of *Caulerpa* in San Diego, Orange, and Los Angeles counties in southern California during both pre-ban surveys in 2000–2001 (*grey bars*) and post-ban surveys in 2005–2006 (*black bars*). Data for 2000–2001 were obtained from Zaleski and Murray (2006). Indicated above *each bar* is the number of stores selling *Caulerpa* over the total number of stores visited. χ^2 tests revealed no difference for San Diego County ($\chi^2 = 2.216$, $df = 1$, $P = 0.142$), Orange County ($\chi^2 = 0.383$, $df = 1$, $P = 0.535$), and the total of all counties ($\chi^2 = 0.021$, $df = 1$, $P = 0.886$) while a significant increase in availability was observed in Los Angeles County ($\chi^2 = 3.838$, $df = 1$, $P = 0.005$)

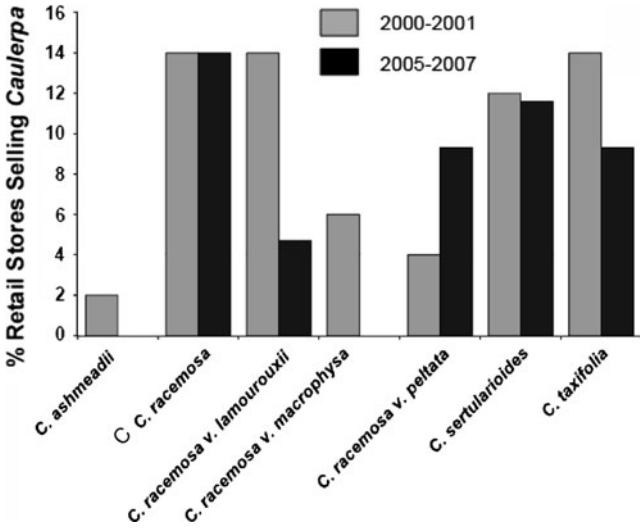

Fig. 2 Percentage of stores selling *Caulerpa* species currently on the California state ban list during both pre-ban surveys in 2000–2001 (50 stores sample, *grey bars*) and post-ban surveys in 2005–2006 (43 stores surveyed, *black bars*). Data for 2000–2001 were obtained from Zaleski and Murray (2006). χ^2 tests revealed no significant change in availability between sampling dates (χ^2 $P > 0.100$ in all cases)

A slight decrease in the number of *Caulerpa* taxa sampled from the surveyed stores was found over the period of study. In 2000–2001, 14 total *Caulerpa* taxa were recorded while only 11 taxa were observed in 2005–2007. Although the percent of now banned species available for sale varied, the frequency of availability of banned species did not change markedly (Fig. 2; χ^2 $P > 0.100$ in all cases).

Discussion

Management of marine ecosystems through regulations of human impacts can be effective in protecting species and ecosystems if correctly designed and implemented. For example, well-enforced no-take MPAs in Italy have been successful in reaching the ecological threshold for fish communities (Guidetti and others 2008) with further support for effective management of fisheries in many other no-take areas around the world (Halpern 2003). However, without adequate enforcement or with poorly designed regulations, management strategies may fail to meet their objectives. For example, long-standing MPAs in southern California were not effective in protecting rocky intertidal flora and fauna likely due lack of the enforcement of collecting regulations (Murray 1998; Smith and others 2008; Ambrose and Smith, unpublished) and because these rocky intertidal MPAs do not prohibit the detrimental impacts of trampling and organism handling (Smith and others 2008; Ambrose and Smith, unpublished).

With exception of a handful of reports discussing the effectiveness of ballast water exchange regulations (e.g., Gray and others 2007; Ruiz and Reid 2007), minimal studies have attempted to test the effectiveness of state and federal regulations on the transport of invasive aquatic species, particularly using information prior to and following enacting of a regulation. In the cases of the aquarium trade as a vector, examining the availability of banned non-marine species after the laws have been passed has suggested that regulations are not effective. For example, in Minnesota, the availability and ease of purchase of illegal aquatic plants indicates that compliance with state and federal laws is low (Maki and Galatowitsch 2004). In California, federal regulations have not prevented the sale of Giant *Salvina*, an aquatic species on the Federal Noxious Weeds List, which was found to be available in more than sixty cities in the state (Mullin and others 2000). Kay and Hoyle (2001) also discuss the shortcomings of federal and state regulations as many banned aquatic and wetland weeds were available for purchase through mail-order and ecommerce. In our study, surveys of the availability of the marine *Caulerpa* species in aquarium retail stores prior to a California ban on the possession or sale of these seaweeds provided a unique opportunity to robustly determine the effectiveness of this regulatory strategy using data before and after enacting of the law. Our results give further support suggesting ineffectiveness of bans on aquarium traded species with the California ban failing to eliminate the distribution of *Caulerpa* by the southern California aquarium industry. Despite the statewide ban on several *Caulerpa* species, *C. taxifolia* and other banned *Caulerpa* species continue to be traded at similar frequencies ($\sim$ 50 % of stores sampled) four years following the ban to those established prior to regulation enactment.

In recent years, the aquarium retail industry has received increasing attention as a potential vector for aquatic biological invasions, particularly in marine and freshwater systems. This industry is thought to have an annual trade in marine ornamentals in several hundreds of millions of US dollars per year (Wabinitz and others 2003; Bolton and Graham 2006; Hardin and others 2008). In freshwater systems, aquarium releases have been reported as a likely source for numerous potential and actual fish (Courtenay and Robins 1973; Courtenay and others 1974; Courtenay and Stauffer 1990; Chang and others 2009; Fuller and others 1999; Copp and others 2010; Strecker and others 2011), invertebrate (Fofonoff and others 2009), and plant (Fofonoff and others 2009) invasions, including those via e-commerce (Walters and others 2006; Magalhães and Jacobi 2010). In contrast, for marine systems, only a few cases trace introductions to the aquarium industry, including the introductions of *Caulerpa* (Meinesz and Hesse 1991) and, likely, the lionfish (Whitfield and others 2002).

However, several other introductions are thought to have been brought about by the aquarium trade (Semmens and others 2004; Bolton and Graham 2006). For example, Semmens and others (2004) suggest that a relative high number (16 species) of non-native saltwater tropical fish in Florida have been introduced through aquarium dumping due to patterns in fish location, magnitude of importation, and shipping pathways, another possible source of introduction. The international trade of live rock in the aquarium industry, not regulated in most regions, has also been recognized as a threat (Padilla and Williams 2004; Bolton and Graham 2006; Walters and other 2006); live rock trade can inadvertently transport unwanted organisms that live on the rock. For example, the non-native upside down jellyfish, *Cassiopea*, was reported to have been transported to the U.S. via live rock although evidence of its release into the wild from this source is lacking (Bolton and Graham 2006).

In addition to aquarium retail stores, internet commerce has provided the wide availability of potentially invasive algal and invertebrate species, including *C. taxifolia* (Walters and others 2006). The continued availability of prohibited species found in our study suggests limited effectiveness of the California ban on *Caulerpa* spp. Together with findings by Walters and others (2006), which demonstrate the widespread ability to purchase non-native seaweeds and other marine species through internet commerce, these results underscore a strong need for the internal regulation of industries that distribute marine ornamental species. In contrast, the failure to find the aquarium strain of *C. taxifolia* in this study (based on morphological characteristics) or in Walters and others (2006) and Zaleski and Murray (2006) (based on genetic sequencing; see Stam and others 2006) suggests management success in controlling this particular strain.

While *C. taxifolia* is well understood as a potential invader, it is important to consider the threat posed by other species in the genus with the potential to invade temperate zones, including California. Numerous other *Caulerpa* species, including *C. racemosa* subspecies, *C. scalpelliformis*, *C. brachypus*, and *C. filiformis,* have invaded other regions of the world (Davis and others 1997; Verlaque and others 2003, 2004; Jacoby and others 2004; Ruitton and others 2005; Cummings and Williamson 2008). In the previous study by Zaleski and Murray (2006), distributions of the 11 taxa found in aquarium retail stores included at least 8 that have geographic distributions extending into temperate waters. Our study revealed that the same 8 species with temperate extensions to their distributions continued to be sold in southern California retail stores. The commercial availability of these species poses a serious threat to local waters if they were to be released.

The reason for lack of compliance with the California ban is unknown and worthy of exploration; however, lack of enforcement, inability to identify the difference between banned and legal species, and lack of public awareness likely contribute to the ineffectiveness of the ban. One challenge of the current policy is lack of enforcement of regulations prohibiting the sale, transport, and possession of banned *Caulerpa* species. Although it appeared that some aquarium retail stores were unaware of the ban, there were several cases in which *Caulerpa* specimens were sold discretely, suggesting knowledge of the law by store employees. Another challenge is the difficulty in distinguishing morphologically similar species to the untrained eye. Given that *Caulerpa* is difficult for the untrained to identify at the species level using only morphological characteristics, we support the recommendation petitioned to the US Department of Agriculture by Jenkins in 2003 (no action to date) and stated by Stam and others (2006) to eliminate confusion by banning all species as a precautionary policy. This policy has been enacted by the City of San Diego where a weak pattern of higher compliance was observed; within the city, *Caulerpa* was purchased at 3 of 4 stores in 2000-01 but only in one of 4 stores in 2005–07, with an additional store having several species in stock but not for sale.

In addition to banning all species to reduce identification issues, efforts to increase awareness among aquarium hobbyists, retailers, and the public are needed. For other non-native species, public awareness and education has often been a policy recommendation (Courtenay and Robins 1973; Hare and Whitfield 2003; Semmens and others 2004) or a strategy used to reduce additional introductions and halt spread of the species (Hardin 2007; Higgins and others 2007; Strayer 2009), with varying levels of success. Outreach efforts for *Caulerpa*, nationally and statewide in California, were developed by University of Southern California Sea Grant Program and the University of Central Florida initiated in 2006 and by the Southern California Caulerpa Action Team and Merkel and Associates, Inc. in 2006/07 (given the timing of these outreach efforts, they likely had little impact on our results). Outreach included curriculum for K-12 students, and letters, fact sheets, brochures and presentations for aquarium hobbyists and independent retailers. In addition, trainings were held to help California Department of Fish and Game wardens and biologists distinguish between morphologically similar species. The effectiveness of the outreach program is summarized by Walters and others (2011) who maintain that continued education is the best course of action.

Non-native and invasive species management include state and federal laws and regulations designed to reduce the risk of introducing non-native/invasive aquatic species, yet often the effectiveness and compliance with these regulations fail to be evaluated. Our study highlights the

need for effectiveness to be tested. This study provides evidence that the current California state ban on possession and sale of potentially invasive *Caulerpa* species has not been effective.

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References

Abbott IA, Hollenberg GJ (1976) Marine algae of California. Stanford University Press, Stanford

Allen R (2010) International management of tuna fisheries: arrangements, challenges and a way forward. FAO Fisheries and Aquaculture Technical Paper. No. 536

Bax N, Carlton JT, Mathews-Amos A, Haedrich RL, Howarth FG, Purcell JE, Reiser A, Gray A (2001) The control of biological invasions in the world's oceans. Conservation Biology 15:1234–1246

Bolton TF, Graham WM (2006) Jellyfish on the rocks: bioinvasion threat of the international trade in aquarium live rock. Biological Invasions 8:651–653

Carlton JT (2001) Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington

Ceccherelli G, Cinelli F (1997) Short-term effects of nutrient enrichment of the sediment and interactions between the seagrass *Cymodocea nodosa* and the introduced alga *Caulerpa taxifolia* in a Mediterranean bay. Journal of Experimental Marine Biology and Ecology 217:165–177

Chang AL, Grossman JD, Spezio TS, Weiskel HW, Blum JC, Burt JW, Muir AA, Piovia-Scott J, Veblen KE, Grosholz ED (2009) Tackling aquatic invasions: risks and opportunities for the aquarium fish industry. Biological Invasions 11:773–785

Copp GH, Vilizzi L, Gozlan RE (2010) The demography of introduction pathways, propagule pressure and occurrences of non-native freshwater fish in England. Aquatic Conservation: Marine and Freshwater Ecosystems 20:595–601

Courtenay WR, Robins CR (1973) Exotic aquatic organisms in Florida with emphasis on fishes: a review and recommendations. Transactions of the American Fisheries Society 102:1–12

Courtenay WR, Stauffer JR (1990) The introduced fish problem and the aquarium fish industry. Journal of the World Aquaculture Society 21:145–159

Courtenay WR, Sahiman HF, Miley WW II, Herrema DJ (1974) Exotic fishes in fresh and brackish waters of Florida. Biological Conservation 6:292–302

Cummings DO, Williamson JE (2008) The role of herbivory and fouling on the invasive green alga *Caulerpa filiformis* in temperate Australian waters. Marine & Freshwater Research 59:279–290

Davis AR, Roberts DE, Cummins SP (1997) Rapid invasion of a sponge-dominated deep-reef by *Caulerpa scalpelliformis* (Chlorophyta) in Botany Bay, New South Wales. Australian Journal of Ecology 22:146–150

de Villèle X, Verlaque M (1995) Changes and degradation in a *Posidonia oceanica* bed invaded by the introduced tropical alga *Caulerpa taxifolia* in the north western Mediterranean. Botanica Marina 38:79–87

Eldredge LG, Carlton JT (2002) Hawaiian marine bioinvasions: a preliminary assessment. Pacific Science 56:211–212

Fofonoff PW, Ruiz GM, Hines AH, Steves BD, Carlton JT (2009) Four centuries of biological invasions in tidal waters of the Chesapeake Bay region. In: Rilov G, Crooks JA (eds) Biological invasions in marine ecosystems. Springer, Berlin, pp 479–506

Fuller PL, Nico LG, Williams JD (1999) Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication 27

Gambell R (1993) International management of whales and whaling: an historical review of the regulation of commercial and aboriginal subsistence whaling. Arctic 46:97–107

Gray DK, Johengen TH, Reid DF, MacIsaac HJ (2007) Efficacy of open-ocean ballast water exchange as a means of preventing invertebrate invasions between freshwater ports. Limnology and Oceanography 52:2386–2397

Guidetti P, Milazzo M, Bussotti S, Molinari A, Murenu M, Pais A, Spanò N, Balzano R, Agardy T, Boero F, Carrada G, Cattaneo-Vietti R, Cau A, Chemello R, Greco S, Manganaro A, Notarbartolo di Sciara G, Russo GF, Tunesi L (2008) Italian marine reserve effectiveness: Does enforcement mater? Biological Conservation 141:699–709

Halpern B (2003) The impact of marine reserves: Do reserves work and does reserve size matter? Ecological Applications 13:S117–S137

Hardin, S (2007) Managing non-native wildlife in Florida: state perspective, policy and practice. In: Witmer GW, Pitt WC, Fagerston KA (eds) Managing vertebrate invasive species: proceedings of an international symposium. National Wildlife Research Center, Fort Collins

Hardin S, Watson C, Zajicek P (2008) Pathway risk analysis for exotic ornamental marine and estuarine species. Technical Report for the Florida Department of Agriculture and Consumer Services

Hare JA, Whitfield PE (2003) An integrated assessment of the introduction of lionfish (*Pterois volitans/miles* complex) to the western Atlantic Ocean. NOAA Technical Memorandum NOS NCCOS 2

Harlioglu MM, Harlioglu AG (2006) Threat of non-native crayfish introductions in Turkey: global lessons. Reviews in Fish Biology and Fisheries 16:171–181

Hayes KA, Joshi RC, Thiengo SC, Cowie RH (2008) Out of South America: multiple origins of non-native apple snails in Asia. Diversity and Distributions 14:701–712

Higgins A, Serbesoff-King K, King M, O'Reilly-Doyle K (2007) The power of partnerships: landscape scale conservation through public/private collaboration. Natural Areas Journal 27:236–250

Hockings M, Stolton S, Leverington F, Dudley N, Courrau J (2006) Evaluating effectiveness: a framework for assessing management effectiveness of protected areas, 2nd edn. IUCN, Gland, Switzerland/Cambridge, p 105

Jacoby C, Lapointe B, Creswell L (2004) Are native and nonindigenous seaweeds overgrowing Florida's east coast reefs? Florida Sea Grant College Program

Jousson O, Pawlowski J, Zaninetti L, Zechman FW, Dini F, Di Guiseppe G, Woodfield R, Millar A, Meinez A (2000) Invasive alga reaches California. Nature 408:157–158

Kay SH, Hoyle ST (2007) Mail order, the internet and invasive aquatic weeds. Journal of Aquatic Plant Management 39:88–91

Levi F, Francour P (2004) Behavioral response of *Mullus surmuletus* to habitat modification by the invasive macroalga *Caulerpa taxifolia*. Journal of Fish Biology 64:55–64

Magalhães ALB, Jacobi CM (2010) E-commerce of freshwater aquarium fishes: potential disseminator of exotic species in Brazil. Acta Scientiarum Biological Sciences 32:243–248

Maki K, Galatowitsch S (2004) Movement of invasive aquatic plants into Minnesota (USA) through horticulture trade. Biological Conservation 118:389–396

McMurray CA (2009) Wildlife trafficking: U.S. efforts to tackle a global crisis. Natural Resources and Environment 23:16–18

McNeely JA (2005) Human dimensions of invasive alien species. In: Mooney HA, Mack RN, McNeely JA, Neville LE, Schei PJ, Waage JK (eds) Invasive alien species. Island Press, WA, pp 285–309

Meinesz A, Hesse B (1991) Introduction et invasion de l'algue tropicale *Caulerpa taxifolia* en Méditerranée Nord-occidentale. Oceanologica Acta 14:415–426

Meinesz A, Belsher T, Thibaut T, Antolic B, Ben Mustapha K, Chiaverini D, Cinelli F, Cotallorda J, Djellouli A, El Abed A, Orestano C, Grau A, Ivesa L, Jaklin A, Langar H, Massuti-Pascual E, Peirano A, Tunesi L, De Vaugelas J, Zavodnik N, Zuljevic A (2001) The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. Biological Invasions 3:201–210

Merkel and Associates, Inc. (2006) Final Report on the eradication of the invasive seaweed *Caulerpa taxifolia* from Agua Hedionda lagoon and Huntington harbour, California. Technical report prepared for Steering Committee of the Southern California Caulerpa Action Team

Mullin BH, Anderson LW, Ditomaso JM, Eplee RE, Getsinger KD (2000) Invasive plant species. Council for Agricultural Science and Technology, Issue Paper 13

Murray SN (1998) Effectiveness of marine life refuges on southern California shores. In: Magoon OT, Converse H, Baird B, Miller-Henson M (eds) California and the world ocean '97. Taking a look at California's ocean resources: an agenda for the future. American Society of Civil Engineers, Reston, pp 1453–1465

Murray SN, Fernandez L, Zertuche-Gonzalez JA (2007) Status, environmental threats, and policy considerations for invasive seaweeds for the Pacific Coast of North America. Commission on Environmental Cooperation, Montreal

Padilla DK, Williams SL (2004) Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. Frontiers in Ecology and the Environment 2:131–138

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53–65

Ribera Siguan MA (2003) Pathways of biological invasions of marine plants. In: Ruiz GM, Carlton J (eds) Invasive Species: vectors and management strategies. Island Press, Washington, DC, pp 183–226

Ruitton S, Javel F, Culioli J, Meinesz A, Pergent G, Verlaque M (2005) First assessment of the *Caulerpa racemosa* (Caulerpales, Chlorophyta) invasion along the French Mediterranean coast. Marine Pollution Bulletin 50:1061–1068

Ruiz GM, Carlton JT, Grosholz ED, Hines AH (1997) Global invasions of marine and estuarine habitats by non-indigenous species: mechanism, extent, and consequences. American Zoologist 37:621–632

Ruiz GM, Fofonoff PW, Carlton JT, Wonham MJ, Hines AH (2000) Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. Annual Review of Ecology and Systematics 31:481–531

Ruiz GM, Reid DF (2007) Current state of understanding about the effectiveness of ballast water exchange (BWE) in reducing aquatic nonindigenous species (ANS) introductions to the Great Lakes Basin and Chesapeake Bay, USA: synthesis and analysis of existing information. National Ocean and Atmospheric Administration Technical Memorandum

Schaffelke B, Murphy N, Uthicke S (2002) Using genetic techniques to investigate the sources of the invasive alga *Caulerpa taxifolia* in three new locations in Australia. Marine Pollution Bulletin 44:204–210

Semmens BX, Buhle ER, Salomon AK, Pattengill-Semmens CV (2004) A hotspot of non-native marine fishes: evidence for the aquarium trade as an invasion pathway. Marine Ecology Progress Series 266:239–244

Smith JR, Fong P, Ambrose RF (2008) The impact of human visitation on mussel bed communities along the California coast: Are regulatory marine reserves effective in protecting these communities? Environmental Management 41:599–612

Stam WT, Olsen JL, Zaleski SF, Murray SN, Brown KR, Walters LJ (2006) A forensic and phylogenetic survey of *Caulerpa* species (Caulerpales, Chlorophyta) from the Florida coast, local aquarium shops, and e-commerce: establishing a proactive baseline for early detection. Journal of Phycology 42:1113–1124

Strayer DL (2009) Twenty years of zebra mussels: lessons from the mollusk that made headlines. Frontiers in Ecology and the Environment 7:135–141

Strecker AL, Campbell PM, Olden JD (2011) The aquarium trade as an invasion pathway in the Pacific Northwest. Fisheries 36:74–85

Szaro RC, Sexton WT, Malone CR (1998) The emergence of ecosystem management as a tool for meeting people's needs and sustaining ecosystems. Landscape and Urban Planning 40:1–7

Verlaque M, Fritayre P (1994) Modifications des communautés algales méditerranéennes en presence de l'algue envahissante *Caulerpa taxifolia* (Vahl) C. Agardth. Oceanologica Acta 17:659–672

Verlaque M, Durand C, Huisman JM, Boudouresque CF, le Parco Y (2003) On the identity and the origin of the Mediterranean invasive *Caulerpa racemosa* (Caulerpales, Chlorophyta). European Journal of Phycology 38:325–339

Verlaque M, Afonso-Carillo J, Gil-Rodríguez MC, Durand C, Boudouresque CF, Le Parco Y (2004) Blitzkrieg in a marine invasion: *Caulerpa racemosa* var. *cylindracea* (Bryopsidales, Chlorophyta) reaches the Canary Islands (north-east Atlantic). Biological Invasions 6:269–281

Wabinitz C, Taylor M, Green E, Razak T (2003) From ocean to aquarium. UNEP WCMC, Cambridge

Walters LJ, Brown KB, Stam WT, Olsen JL (2006) E-commerce and *Caulerpa*: unregulated dispersal of invasive species. Frontiers in Ecology and the Environment 4:75–79

Walters LJ, Odom R, Zaleski S (2011) The aquarium hobby industry and invasive species: Has anything changed? Frontiers in Ecology and the Environment 9:206–207

Whitfield PE, Gardner T, Vives SP, Gilligan MR, Courtenay WR Jr, Ray GC, Hare JA (2002) Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic coast of North America. Marine Ecology Progress Series 235:289–297

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E (1998) Quantifying threats to imperiled species in the United States. BioScience 48:607–614

Zaleski SF, Murray SN (2006) Taxonomic diversity and geographic distributions of aquarium traded species of *Caulerpa* (Cholorphyta: Caulerpaceae) in southern California, USA. Marine Ecology Progress Series 314:97–108