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# E-commerce and *Caulerpa*: unregulated dispersal of invasive species

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Professional aquarists and hobbyists are thought to be the source of invasions of the aquarium strain of the green macroalga *Caulerpa taxifolia* in the Mediterranean, southern California, and Australia. The US Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS) restricted interstate commerce and importation of the Mediterranean clone of *C taxifolia* prior to the California invasion and is currently deciding if it should strengthen regulation of this genus as more species of *Caulerpa* are being described as invasive. Here we document the importance of e-commerce as a mode of dispersal for many species of *Caulerpa* in the United States. We purchased *Caulerpa* from 30 internet retailers and 60 internet auction sites representing 25 states and Great Britain. Twelve different *Caulerpa* species were confirmed using DNA sequencing. Only 10.6% of sellers provided the correct genus and species names with their shipments. Thirty purchases of “live rock” provided four species of *Caulerpa*, as well as 53 additional marine species. Our results confirm the extensive e-commerce availability of this invasive genus and its high dispersal potential via postal services and hobbyists. We recommend that both eBay and the USDA maximize regulation of *Caulerpa*.

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Many species of the green macroalga *Caulerpa* (Chlorophyta: Ulvophyceae) are highly invasive and the economics and ecological impacts associated with these introductions are well documented (eg de Villèle and Verlaque 1995; Davis *et al.* 1997; Meinesz 1999; Williams and Grosholz 2002a). For example, monocultures of the aquarium strain of *Caulerpa taxifolia* extend hundreds of kilometers along the Mediterranean coastline (Meinesz *et al.* 2001), have clogged nine waterways in New South Wales and two more in South Australia (Schaffelke *et al.* 2002; Millar 2004; A Davis pers comm), and infested two lagoons in southern California (Jousson *et al.* 2000). In all cases, this invasive strain of *C taxifolia* grew faster, larger, and in deeper and colder waters than its native tropical counterpart (Belsher and Meinesz 1995; Williams and Grosholz 2002b). DNA studies confirmed that the aquarium strain of *C taxifolia* originated near Brisbane, Australia, and was subsequently transported via the aquarium trade (Jousson *et al.* 1998; Wiedenmann *et al.* 2001; Muesnier *et al.* 2002). In the Mediterranean and the Canary Islands, *Caulerpa racemosa* is now also recognized as invasive (Verlaque *et al.* 2003, 2004). Similarly, non-native *Caulerpa brachypus* was first recognized in southeastern Florida waters in 2001, where extensive blooms were overgrowing or displacing native flora and fauna (Jacoby *et al.* 2004).

Despite its invasive reputation, many members of the genus *Caulerpa* (especially *C racemosa*, *C prolifera*, and

some of the “feather *Caulerpas*”: *C taxifolia*, *C sertularioides*, and *C mexicana*) remain extremely popular with aquarium hobbyists because they are attractive in salt water tanks and are easy to clonally propagate (Smith and Walters 1999; Padilla and Williams 2004). The genus *Caulerpa* is also touted by hobbyists for its many additional virtues, most notably its ability to remove nutrients from closed aquarium systems and to act as fish food. However, as their aquaria become overgrown or situations change, hobbyists may either sell their extra stock on eBay or dispose of their unwanted algae (and animals) in nearby waters, thus setting the stage for a new invasion (Whitfield *et al.* 2002; Semmens *et al.* 2004).

“Live rock” is extremely popular with aquarists because it is inexpensive, and can potentially harbor a huge diversity of marine organisms (including *Caulerpa* spp). Many consider it to be an essential component of saltwater aquariums, as it acts as a substrate for sessile species, a refuge for fishes and mobile invertebrates, and as a biological filtration system. Live rock consists of either pieces of hard coral directly harvested from reefs or rocks allowed to cure under aquaculture conditions.

In response to a stakeholder request, the Mediterranean clone of *C taxifolia* was added to the Noxious Species List in 1999 by the US Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS), making interstate transport and importation illegal. Only the Mediterranean clone was included in this initial request. The term “Mediterranean clone” has been replaced by the more neutral “aquarium strain” by many scientists, and this term will be used here.

In 2001, California imposed stricter guidelines than the Federal Government in response to the two southern

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Californian invasions by the aquarium strain of *C. taxifolia*; it became illegal to sell or possess *C. taxifolia* or eight other species, some of which are easily confused with *C. taxifolia* (*C. mexicana*, *C. sertularioides*, *C. ashmeadii*, *C. floridana*, *C. cupressoides*), and others that are considered invasive (*C. racemosa*, *C. scalpelliformis*, *C. verticillata*). The city of San Diego took this a step further and made it illegal to possess any species of *Caulerpa*. There has been local success in eradicating *Caulerpa* in southern California, but at a cost of over \$5 million (R Woodfield pers comm). Now a more concerted approach is necessary at the national level. The Aquatic Nuisance Species (ANS) Task Force released a National Management Plan for the genus *Caulerpa* in the fall of 2005, focused on supporting *Caulerpa* research and outreach, and the USDA–APHIS is currently considering whether to enhance regulation of this genus. Although both the ANS Task Force and USDA–APHIS acknowledge the potential importance of e-commerce as a mode of dispersal for these species, until now the importance of this vector has not been directly measured.

### ■ Methods

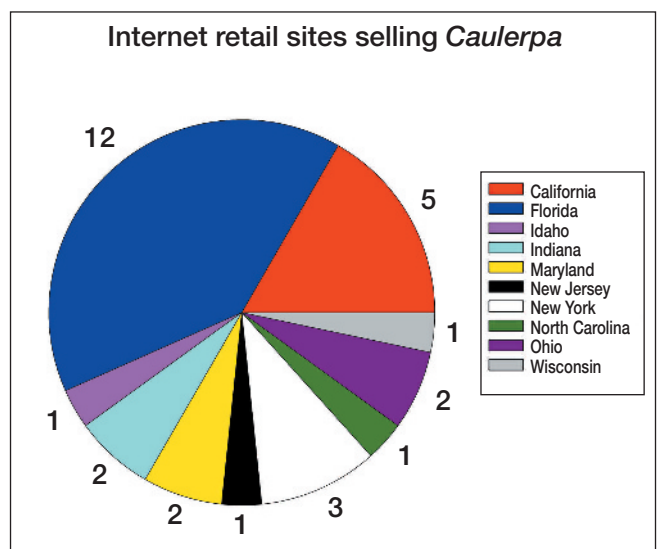
Between April 2003 and April 2005, using our central Florida address, we determined the diversity and availability of *Caulerpa* species via e-commerce and local retail outlets. The study involved 22 volunteers and over 200 internet search hours; we therefore consider our findings to be representative of the online availability of the genus. Volunteers chose their search dates and each time a volunteer began a search, he/she had 48 hours to find all the sources of *Caulerpa* available via online retail and eBay auctions, using their own choice of keywords. Keywords ranged from the obvious (eg *Caulerpa*, macroalgae) to less obvious terms, such as refugia, sea grapes, or marine cactus. Online purchases were made once from each dealer with any species of *Caulerpa* in stock, and from all unique eBay auctions that we won between March 11 and November 16, 2004 and between February 1 and March 18, 2005. We purchased *Caulerpa* from 51% of the online retailers we identified (*Caulerpa* was frequently out of stock) and 44% of the auctions. In addition, we obtained *Caulerpa* spp from 25 of 47 (53%) salt-water aquarium retail shops in central Florida (all Yellow Page-listed shops in the Tampa, Orlando, and Daytona Beach areas). We compared our data to those of Zaleski and Murray (in press), who conducted a similar survey of 50 southern California retailers between November 2000 and August 2001.

To determine the likelihood of purchasing live rock with *Caulerpa* growing on it, we purchased rocks from ten online retailers, ten eBay auctions, and ten local retailers during the same periods as described above. On the internet, “live rock” was the only keyword we used and we purchased it from the first ten retailers and eBay auctions we encountered that would sell us quantities of 10 kg or less.

Many distributors only wanted to supply 100 kg or more, shipped directly from the country of origin. All of the purchased live rock was maintained in separate, recirculating aquaria for 1 month.

### ■ Results and discussion

From 90 internet sites (30 online commercial retailers and 60 eBay auctions), *Caulerpa* spp were shipped to central Florida from shipping addresses in Great Britain and 25 US states, 52% of which were landlocked (Figures 1 and 2). Figures 1 and 2 document extensive interstate transport of this genus, especially via eBay. We separated our purchases into online retail versus eBay auctions for two reasons. First, internet retailers should be aware of federal regulations pertaining to the organisms they sell as part of their livelihood, while this may or may not be the case with eBay vendors, many of whom are home hobbyists. Information about restrictions on shipping *Caulerpa* to California was found on only two of the 30 retail websites from which we purchased material. eBay states that sellers are responsible for knowing all federal and state regulations for all live plants, animals, or animal products they sell and that vendors stand to have their accounts suspended and forfeit all eBay fees on the cancelled listings for breaking federal regulations. Of the 60 eBay auctions we won, only three vendors included information showing that they were aware of the restrictions on interstate transport of *Caulerpa*. In addition, one eBay vendor of *C. prolifera* proudly, and correctly, stated that this species was permitted in, and could be shipped to, California. We never saw the aquarium strain of *C. taxifolia* specifically listed on eBay, but “feather *Caulerpa*” was frequently seen for sale. Twelve of the 30 internet retailers were located in Florida and collected macroalgae locally, on demand. We also bought from two out-of-state retailers that supply live



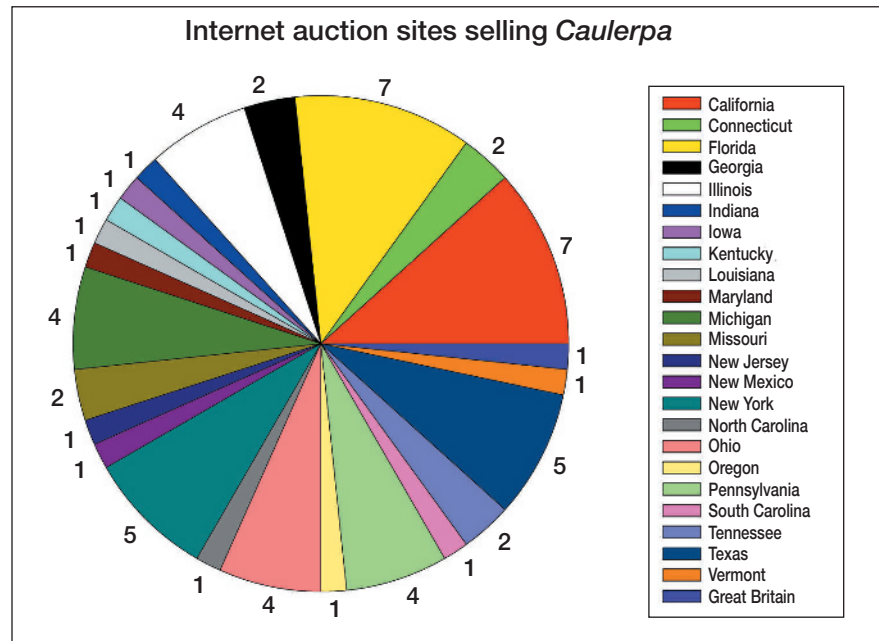
**Figure 1.** States with *Caulerpa* available for purchase from commercial internet retailers. Numbers associated with pie-charts indicate the number of retailers.

materials to educational institutions that contracted with south Florida harvesters to supply *Caulerpa* as needed. Thus, 47% of our internet retail purchases never crossed state lines. *Caulerpa* spp were purchased from seven eBay auctions listing Florida as their address (12%). This suggests much greater interstate dispersal of *Caulerpa* from eBay auctions than from internet retailers. It is also important to note that all of our purchases were delivered via the US postal service or one of many private shipping services; USDA–APHIS has no direct regulatory inspection authority over these entities.

*Caulerpa* costs varied greatly among sellers, with the least expensive being local retailers. The average cost for a handful of any species of the genus *Caulerpa* locally was \$4.00. Not included in this average is the free *Caulerpa* that we received from 43% of the local retailers. We always purchased the smallest amount available online. Units of purchase also varied greatly among dealers, ranging from 2–3 individuals to enough to fill a quart-size plastic bag (22 x 17 cm) to “enough for a class of 35 students”. The average cost for any single species of *Caulerpa* from internet retailers was \$43.08, and \$18.09 from eBay. In both cases, this price included packing and shipping charges, which ranged from \$10 to over \$35 per shipment.

From all purchased material, 13 different *Caulerpa* species were identified by us at the University of Groningen, using DNA sequencing (Figure 3). Details of all sequences and relationships for all collections, along with those of Zaleski and Murray (in press), will soon be submitted to GenBank and for publication (Stam *et al.* unpublished). Four species were available from all sources, whereas *C. cupressoides* was only available via the internet (Figure 3). Of the 12 species shipped to central Florida, two species, *Caulerpa serrulata* and *C. taxifolia*, have not been reported in Florida’s coastal waters (Littler and Littler 2000; C Glardon pers comm).

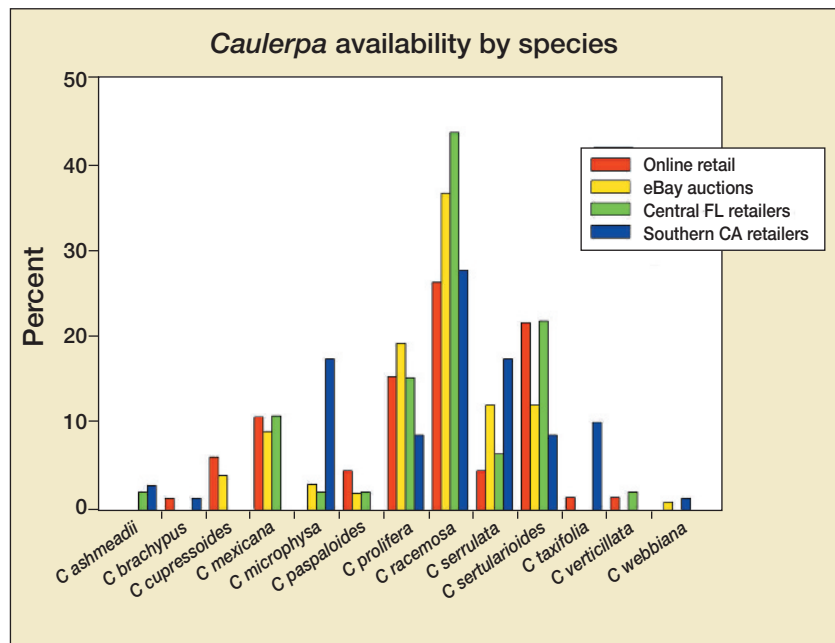
Specimens of *C. taxifolia* were purchased only once, from a southern California internet retailer (November 2004) and were listed online as “green feather *Caulerpa*”. It proved to be the non-invasive type, based on DNA sequence analysis (Stam *et al.* unpublished). The one finding of *C. taxifolia* suggests that this species is not being widely distributed in the US via e-commerce, hopefully as a result of awareness campaigns and USDA–APHIS regulations. The potential success of this early (pre-California invasion) USDA decision to restrict the aquarium strain of *C. taxifolia* indicates that a genus-wide ban could be very effective in preventing future invasions and associated, extremely costly eradication efforts.



**Figure 2.** States/countries with *Caulerpa* available for purchase from eBay auctions. Numbers associated with pie-charts indicate the number of auctions.

Reported origins of live rock included Haiti, the Caribbean, Florida Keys, Marshall Islands, Pohnpei, Fiji, Tonga, Samoa and Vanuatu. Following one-month laboratory cultivation, we observed *C. racemosa*, *C. sertularioides*, *C. mexicana*, and *C. verticillata*, plus 25 other species of macroalgae, 27 species of invertebrates, and multiple species of cyanobacteria. In many cases, *Caulerpa* was not visible on the rocks until the fourth week of cultivation. Costs of live rock ranged from \$20.29 per pound from internet retailers, \$6.82 per pound from eBay vendors (both include shipping), to \$7.23 per pound from local retailers.

From our e-commerce purchases, we learned that both retailers and eBay vendors frequently do not identify their product scientifically, by including the genus and species (14.1% included both genus and species). When all purchases were considered, sellers correctly identified *Caulerpa* at the species level only 10.6% of the time. Misidentifications at the species level occurred 3.5% of the time (all associated with “feather *Caulerpa*s”), while only the name *Caulerpa* (or green *Caulerpa* or *Caulerpa* algae) was used 15.7% of the time. The genus name *Caulerpa* plus a common name descriptor (eg grape *Caulerpa*, feather *Caulerpa*) was used in 44.4% of cases, while only a common name (eg grape weed, fern algae, etc) was used 11.1% of the time. The term “green macroalgae” was used 5.1% of the time and the term “fish food” was used on one occasion. At the genus level, mistakes occurred in 9.6% of cases. This is in part because *Caulerpa* is a popular internet keyword, which encourages sellers to mislabel their stock. We found: “red grape *Caulerpa*” (actually *Botrycladia*), “red feather *Caulerpa*” (actually *Gelidiella*), “red *Gracilaria Caulerpa*” (actually *Gracilaria*), “lettuce *Caulerpa*” (actually *Ulva*), “*Caulerpa Halimeda* macroalgae” (actually *Halimeda opuntia*), and



**Figure 3.** Percent availability of *Caulerpa* species from eBay auctions and online, Central Florida, and Southern California retail sources.

“*Chaetomorpha Caulerpa*” (actually *Chaetomorpha*). This high level of unreliability and variability makes both morphological identification by customs agents and internet tracking of *Caulerpa* difficult.

Finally, we discovered that *Caulerpa*, especially species of *Caulerpa* with feathery blades, was frequently pictured in entire aquarium set-ups for sale on internet auction sites. Items had to be collected in person, so we were able to acquire *C. racemosa* and *C. mexicana* by this means from only one auction initiated in Clermont, Florida. In total, ten states were represented in 13 auctions for complete, 30–120-gallon tank set-ups.

### ■ Improving the future

Internet availability of the genus *Caulerpa*, as well as numerous other algal species and invertebrates, represents a serious threat to Florida’s coastlines in terms of non-native introductions from hobbyists. The \$5 million spent on *Caulerpa* eradication in California would be equivalent to 142 857 purchases of loose *Caulerpa* at an average of \$35 per purchase. If 1% of these hobbyists dumped *Caulerpa* into nearby waters and 1% of these releases became established, then at least \$70 million (14 eradications x \$5 million/response) will be required to achieve eradication. Pressuring eBay to eliminate all auctions of *Caulerpa* and enhanced federal regulation of *Caulerpa* would be considerably more cost-effective.

Commercial retail of invasive species is not limited to marine macroalgae or live rock. For example, Semmens et al. (2004) found 16 species of non-native, marine fishes in Florida waters; their data suggest aquarium dumping as the source for all these species. Only limited information was available online and in local retail shops to alert con-

sumers to the dangers of “aquarium dumping”. Locally, only two of 47 retailers had signs asking patrons not to dump unwanted organisms. On the internet, we found only six distributors (five retailers, one eBay auction) who warned against aquarium dumping. This limited amount of warning on improper disposal of unwanted marine organisms indicates that more and better outreach is needed. A new website, [www.habitattitude.net](http://www.habitattitude.net), was recently created for just this reason. This national initiative has been developed by the ANS Task Force and the aquarium, pet, nursery, and landscape industries to raise consumer awareness about invasive species and alternatives to release of unwanted organisms into the wild. A number of other partners are also involved, including US and state-level Fish and Wildlife Services and the National Sea Grant College Program. By engaging and receiving support from the

industries that distribute non-native flora and fauna for the first time, this outreach program has a much greater chance of success than previous federal and state-level efforts that operated on a more confrontational level. To date, only a limited number of retail outlets and suppliers have shown interest, but expectations are high that this campaign will help reduce the number of releases of invasive species in terrestrial, fresh, and marine systems.

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