MARINE CONSERVATION

SCIENCE, POLICY, AND MANAGEMENT

G. Carleton Ray and Jerry McCormick-Ray
Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia, USA

Illustrations by Robert L. Smith, Jr.

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Fig. 8.21 Installing culverts under roads increases hydrologic connectivity between wetlands and the ocean. These projects are a common form of ecosystem restoration in The Bahamas. Photograph courtesy C. R. Layman.

8.3.4 Invasion of Bahamian coral reefs by predatory Pacific red lionfish

Mark A. Hixon
University of Hawai'i at Manoa, Honolulu, Hawai'i, USA

Mark A. Albins
Marine Fish Laboratory, Auburn University, Fairhope, Alabama, USA

8.3.4.1 The issue

The threat of invasive species in marine ecosystems has recently been brought to the conservation forefront by the introduction, rapid spread, and expanding ecological effects of Pacific red lionfish (*Pterois volitans*) in The Bahamas and Greater Caribbean region (Fig. 8.22). Lionfish were accidentally or intentionally released from aquaria, and first noted off southeast Florida in the mid-1980s (Whitfield *et al*., 2002; Schofield, 2009, 2010). Lionfish were first confirmed in The Bahamas in 2004 (Snyder and Burgess, 2007), underwent a population explosion there by 2007 (Green and Côté, 2008; Albins and Hixon, 2011), and have subsequently spread throughout most of the western tropical Atlantic and Caribbean region, including the Gulf of Mexico (Fig. 8.23; Freshwater *et al*., 2009; Schofield, 2009, 2010). Lionfish now inhabit a broad variety of marine habitats in The Bahamas, ranging from coral reefs (Green and Côté, 2008), to nearby seagrass beds (Claydon *et al.*, 2012) and mangrove tidal creeks (Barbour *et al*., 2010). Although visually appealing, lionfish are proving to be a dire threat to native fishes of The Bahamas (Albins and Hixon, 2008, 2011; Green *et al*., 2012; Albins, 2013).

8.3.4.2 Natural history

Invasive red lionfish reach about 45 cm in length (Akins L, personal communication) and are effective predators of small fishes (Albins and Hixon, 2008; Morris and Akins, 2009; Albins, 2012). They are unique predators for several reasons. Their zebra-like color pattern, combined with their elaborately extended fin spines and rays, may breakup their silhouette, making it difficult for prey to identify them. When sitting still on the reef surface, a lionfish often resembles a clump of seaweed or the frills of a tubeworm, perhaps a form of mimicry (Albins and Hixon, 2011). When stalking prey, lionfish flare their large, fan-like pectoral fins, herd small fish into corners on the reef, and rapidly engulf them by suction feeding (Whitfield *et al*., 2002). Lionfish also often blow a stream of water toward their prey just before striking, which results in the prey fish orienting in an easy-to-swallow, headfirst position (Albins and Lyons, 2012). Atlantic prey fishes have never before encountered lionfish, and native prey appear to take little if any evasive action. This unique combination of characteristics and behaviors may explain why lionfish are able to consume more prey and grow faster than similarly sized native predators (Albins, 2013). Additionally, comparative field observations show that invasive lionfish in The Bahamas and the Cayman Islands consume a broader variety of prey species, and eat larger prey on average, than native lionfish in the Pacific Ocean (Cure *et al*., 2012).

Additionally, invasive lionfish are themselves resistant to predation. Atlantic predatory fishes have thus far largely ignored them. Multiple attempts have been made to feed live and speared lionfish to native sharks and groupers, both in the field and in large outdoor tanks, usually to no avail (Morris, 2009; Raymond *et al.*, in prep.), although Nassau groupers have been trained to eat speared lionfish (personal

Fig. 8.22 The invasive Pacific red lionfish (*Pterois volitans*) on a Bahamian coral reef near Great Exuma. Photograph © Mark Albins.

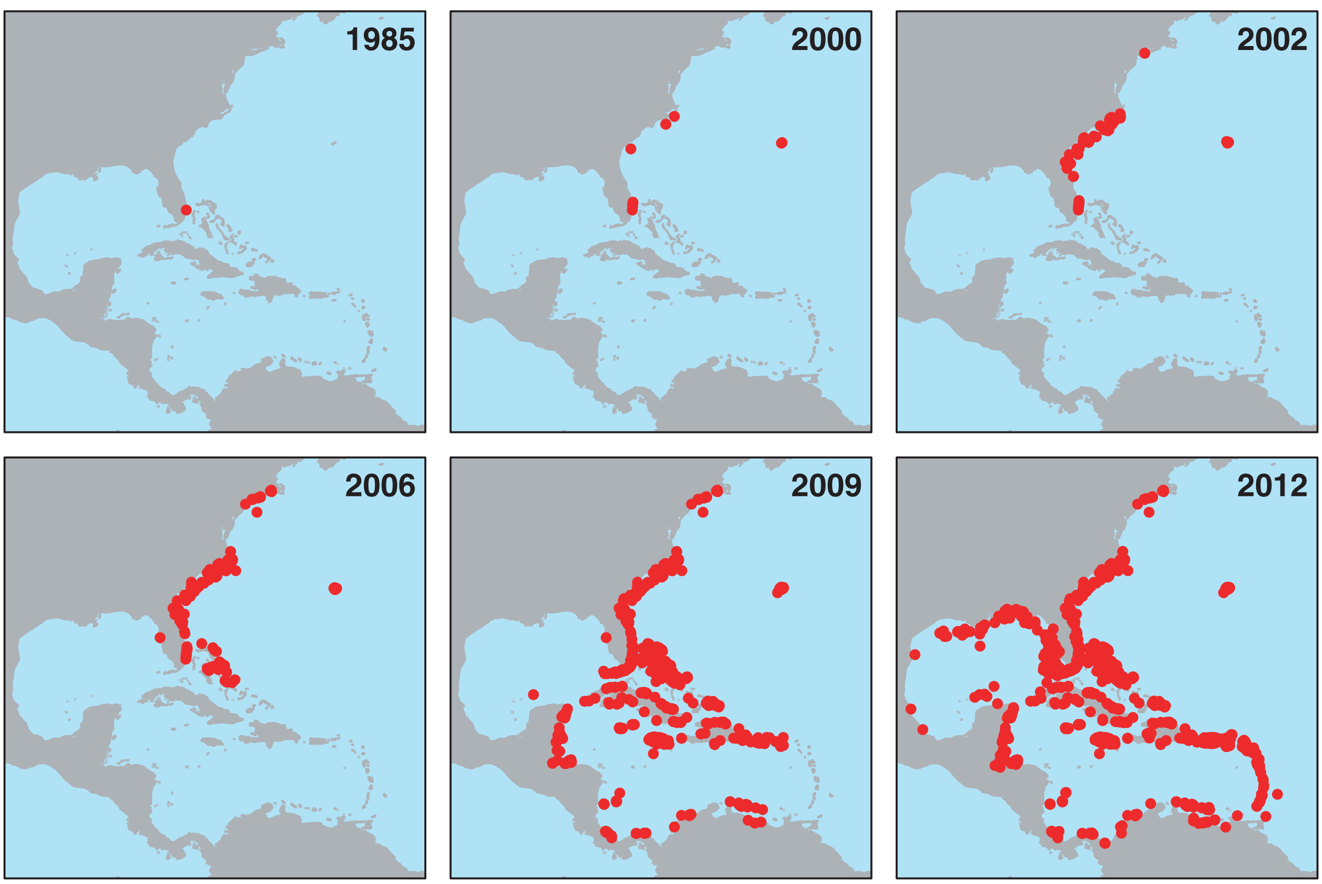

Fig. 8.23 Spread of the lionfish invasion from 1985 to 2012. Data courtesy of Dr. Pamela J. Schofield, USGS Nonindigenous Aquatic Species Database (2012).

observation). Perhaps the unique shape, color, and behavior of lionfish result in native predators not recognizing lionfish as prey. In any case, the numerous venomous spines of lionfish typically thwart those predators that do strike: 13 spines on the dorsal fin, three on the anal fin, and one on each of the paired pelvic fins. However, there are reports of tiger groupers (*Mycteroperca tigris*) and Nassau groupers (*Epinephelus striatus*) captured in The Bahamas with lionfish in their stomachs (Maljković *et al*., 2008). Unfortunately, such larger predators are severely overfished through most of the Caribbean region (Sadovy and Eklund, 1999; Stallings, 2009). Additionally, lionfish in The Bahamas have very low levels of endo- and ecto-parasites that commonly infect native fishes inhabiting the same reefs (Sikkel *et al*., in prep.; Tuttle *et al*., in prep.).

The apparently low risk of predation and low parasite load, combined with high prey consumption rates, may explain the rapid individual growth, high reproductive rate, rapid population growth, and high density of invasive lionfish. Juveniles (<20 cm total length) add about 2 cm to their length monthly (Pusack *et al*., in prep.). Adult females produce more than two million eggs annually (Morris, 2009). Fertilized eggs and developing larvae disperse in ocean currents for about 30 days (Ahrenholz and Morris, 2010). The estimated annual population growth rate throughout the Atlantic and Caribbean from 1992 through 2007 was 67% per year, and was even higher in Exuma Sound (Albins and Hixon, 2011). Densities in The Bahamas have reached more than 390 lionfish per hectare (Green and Côté, 2008)—far greater than in their native Pacific range (Kulbicki *et al*., 2012)—and lionfish have been observed from submersibles at depths greater than 300 m in The Bahamas (R.G. Gilmore, personal communication).

8.3.4.3 Ecological effects

Invasive red lionfish now pose a substantial threat to not only native reef-fish communities (Albins and Hixon, 2008; Albins, 2013), but also indirectly the reefs themselves (Albins and Hixon, 2011). A single lionfish can reduce the number of small fish on a patch reef by about 80% in just a few weeks (Albins and Hixon, 2008). Lionfish consume a broad variety of reef fishes, and smaller lionfish also eat shrimp and other invertebrates (Morris and Akins, 2009). Victims include juveniles of important fishery species, such as groupers and snappers, as well as ecologically important species, such as parrotfishes, that help control algal cover on reefs (Mumby *et al*., 2006). Divers have observed a single lionfish consume more than 20 juvenile reef fish in just 30 minutes (Albins and Hixon, 2008), and average consumption rates throughout the day are on the order of one to two prey per hour (Côté and Maljković, 2010).

A recent field experiment in The Bahamas determined that invasive lionfish might outcompete ecologically similar, native predators (Albins, 2013). The abundance of coney grouper (*Cephalopholis fulva*) and equal-sized lionfish were adjusted on patch reefs in three ways: one lionfish only, one coney only, and one lionfish and one coney together. After two months, coney alone had reduced the abundance of small fish on the reefs by an average of 36%, whereas lionfish alone had reduced prey fish by nearly 94%, over 2.5 times the effect of the native predator. The two species together reduced prey fish abundance to zero, indicating that one and/or both species suffered reduced consumption rates in the presence of the other. Lionfish in this experiment grew more than six times as rapidly as coney.

Ongoing research on the lionfish invasion focuses on four major themes. First, efforts to map and predict the geographic spread of the invasion quickly and accurately are reported in U.S. Geological Survey's Nonindigenous Aquatic Species Program (USGS, online). Oceanographic models predict future patterns of larval dispersal, while population genetics methods track actual patterns of dispersal (Freshwater *et al*., 2009; Betancur *et al*., 2011), and matrix models project future population growth (Morris *et al*., 2011).

Second, studies continue to examine the ecological effects of this invasion on the structure and function of coral-reef ecosystems. Experimental studies in The Bahamas manipulate lionfish abundance relative to potential prey, predators, and competitors, and observational studies and models estimate how lionfish predation is altering biomass and energy flow in coastal food webs.

Third, efforts are underway to determine whether there are any mechanisms of natural resistance to this invasion. Biotic resistance appears to be low, although lionfish are rare on some reefs that tend to be buffeted by strong currents, which may reduce lionfish feeding rates. Perhaps native predators will eventually learn to consume lionfish more efficiently, or native parasites or diseases will ultimately control the invaders.

Fourth, natural mechanisms of population control are being explored. Within its native Indo-Pacific region, the red lionfish is typically rare, even at the geographic center of its range in the Philippines (Kulbicki *et al*., 2012). Understanding whether and why this species is a relatively minor player on its native Pacific reefs may provide insight on how to control the invasion. One hypothesis is that lionfish in the Pacific are limited by early post-settlement predation, when newly settled lionfish (about 2 cm total length) have flexible spines and may be more palatable to predators. If such predation on small lionfish were confirmed in the Pacific, then effective management in the Atlantic would include conservation and enhancement of populations of ecologically similar native predators by means of fishing restrictions and marine reserves.

8.3.4.4 Conservation

The rapid and explosive invasion of red lionfish in The Bahamas has galvanized local and national responses. Joint initiatives among educational institutions, the government, and non-governmental organizations have been organized throughout the invaded region (Morris, 2012). Efforts include broad-reaching educational programs intended to teach citizens about basic lionfish biology, to explain why they are a threat to fisheries resources and the marine environment, and how they can be removed safely, effectively, and efficiently. Recreational divers assist marine scientists studying the invasion. Community events teach people to prepare and eat lionfish safely. A national "Eat Lionfish" campaign in The Bahamas seeks to assure citizens that lionfish are a viable alternative to more traditional food fishes. Lionfish are actually quite tasty, similar to their close relatives, the rockfishes and scorpionfishes (family Scorpaenidae). High-end restaurants have begun serving lionfish as a conservation dish (*The Economist*, online). However, as with native predatory reef fishes, eating lionfish caught in certain areas may cause ciguatera poisoning in humans. While many governments and NGOs are currently encouraging fisheries for lionfish, others caution that the economic benefits gained from such a fishery could encourage people to protect the invasive species, or even spread it to previously uninvaded areas, severely complicating management of the invasion (Nuñez *et al.*, 2012).

Control efforts notwithstanding, the rapid spread, high population sizes, and broad geographic range of invasive lionfish mean that complete eradication is highly unlikely. Until biotic control mechanisms are identified and fostered, there is only one effective means of controlling lionfish densities on shallow reefs: direct removal by divers. Such manual removals require extensive effort, which at high levels will come at a high cost. Lionfish inhabit deep waters that divers cannot reach and also occur on the most remote reefs of the Caribbean. Therefore, even the most comprehensive and effective program of direct removals will need to be sustained indefinitely. Otherwise, removals will be counteracted by reproductive lionfish at deep and remote locations continuing to generate larvae capable of continually re-colonizing more accessible locations.

In the long term, the invasion of Atlantic and Caribbean coral reefs by Pacific red lionfish will culminate in one of two outcomes. First, the invasion may worsen to the point where lionfish densities reach extreme levels and populations of many coral-reef fishes are decimated or even extirpated. Second, some combination of native species (competitors, predators, parasites, and/or diseases) may minimize the ecological effects of the invader (Albins and Hixon, 2011). Meanwhile, the best management strategies are likely to continue to involve organizing direct manual removal programs, fostering lionfish fisheries, and implementing marine reserves, the latter given that relatively intact ecosystems are often more resilient to invasions of exotic species. Only time will tell whether the population explosion of Pacific red lionfish in The Bahamas and Wider Caribbean Region becomes one of the most devastating marine invasions in history.

8.3.5 Social and systemic issues

The previous four issues are examples of specific bio-ecological issues facing The Bahamas. The following, in contrast, are anthropogenic and climate-related issues that tend to be systemic and emergent (Ch. 2), implying that future planning for conservation and management will necessarily be incremental.

8.3.5.1 Fisheries and fishing

The Nassau grouper exemplifies one of the most intractable, chronic challenges facing The Bahamas—fisheries—for which gaps in knowledge of natural history and critical habitats are major impediments. For commercial fisheries as a whole, small-scale foreign poaching and violations by domestic fishermen are difficult to track due to the very large size of the archipelago and remoteness of much of it. Harmful practices have included uses of chemicals, abandonment of traps, harvesting of juveniles, and catches during closed seasons. Some of these are no longer practiced (e.g., use of chemicals). However, regulatory measures are in place only for species of high commercial or sporting value and are handicapped by ineffective enforcement.

Other aspects of fishing represent significant gaps in management. For example, The Bahamas is one of the world's leading destinations for sportfishing, notably for bonefish (*Albula vulpes*), but little is known of the level of fishing pressure bonefish can withstand. The same may be said for open-ocean sport fishing for such large species as billfishes (marlins and sailfishes), even though it is generally agreed by scientists that several of these species are depleted throughout their ranges. Finally, the impacts of subsistence and sport fishing, mostly on reefs, can only be roughly estimated, although by general consensus among scientists and divers, reef fishes appear to be depleted, severely so near centers of population and recreation.

The Department of Marine Resources (DMR) is well aware of these problems, but has to concentrate almost all its efforts on commercial fisheries due to a lack of financial support, infrastructure, and personnel. Landings data highlight several features of management (Fig. 8.24). Lobsters (*Panulirus argus*; Fig. 8.25) are of greatest economic value, B$66.3 million out of a total of B$78 million for all fisheries in 2011; conch is second in value (B$ 5.1 million); third, snappers (B$3.1 million); fourth, Nassau grouper (B$0.86 million). Notably, Nassau grouper landings have declined from 0.79 million pounds in 1965 to 0.25 million pounds in 2011, representing a trend from abundance and overfishing to a need for restoration. Some fisheries species are lumped together, such as "snappers" (*Lutjanus* sp.) due to shortage of resources, symptomatic of DMR's inability to fully record levels of fishing on a biological species level. Similarly, a category of "other" includes many species of high ecological value, e.g., parrotfishes that have high ecological value—in their case, grazing on algae. Such lumping of species presents great difficulties for single species, data-based management. Furthermore, landings data alone usually fail to designate from which populations fish were actually caught. This "real-world" difficulty of species-by-species management is moving the DMR towards a broader approach, one aspect of which being establishment of fishery reserves as a means to restore and enhance fisheries and to maintain habitat and biodiversity (Section 8.4.1).

8.3.5.2 Water resources

Water is a critical resource problem for many island communities, including The Bahamas. Few surface-water streams occur in The Bahamas (Section 8.3.3). A notable exception is West Andros' large watersheds (Fig. 8.18). This largest of Bahamian islands is dominated by wetlands and numerous tidal creeks and has by far the largest groundwater aquifer of The Bahamas.