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Review

# Predatory fish invaders: Insights from Indo-Pacific lionfish in the western Atlantic and Caribbean

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ABSTRACT

The invasion of western Atlantic marine habitats by two predatory Indo-Pacific lionfish, *Pterois volitans* and *P. miles*, has recently unfolded at an unprecedented rate, with ecological consequences anticipated to be largely negative. We take stock of recently accumulated knowledge about lionfish ecology and behaviour and examine how this information is contributing to our general understanding of the patterns and processes underpinning marine predator invasions, and to the specific issue of lionfish management. Lionfish were first reported off Florida in 1985. Since their establishment in The Bahamas in 2004, they have colonised 7.3 million km$^2$ of the western Atlantic and Caribbean region, and populations have grown exponentially at many locations. These dramatic increases potentially result from a combination of life-history characteristics of lionfish, including early maturation, early reproduction, anti-predatory defenses, unique predatory behaviour, and ecological versatility, as well as features of the recipient communities, including prey naïveté, weak competitors, and native predators that are overfished and naïve to lionfish. Lionfish have reduced the abundance of small native reef fishes by up to 95% at some invaded sites. Population models predict that culling can reduce lionfish abundance substantially, but removal rates must be high. Robust empirical estimates of the cost-effectiveness and effects of removal strategies are urgently needed because lionfish management will require a long-term, labour-intensive effort that may be possible only at local scales. The ultimate causes of the invasion were inadequate trade legislation and poor public awareness of the effects of exotic species on marine ecosystems. The lionfish invasion highlights the need for prevention, early detection, and rapid response to marine invaders.



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## 1. Introduction

Species invasions are occurring worldwide at an unprecedented rate and represent a major threat to the world's flora and fauna (Vié et al., 2009; Vitousek et al., 1997). More than half a century ago, Elton (1958) drew attention to the ecological damage caused by non-native species. Since then, two goals have dominated the invasion ecology research agenda: identifying the traits of introduced species that make them likely to become invasive, and the characteristics of ecological communities that make them susceptible or resistant to invasions. General answers to these questions have proven elusive. Different species traits correlate with success at different stages of the invasion process, and these vary broadly among taxa (Cadotte et al., 2006; Kolar and Lodge, 2001). Similarly, attempts to identify the characteristics of native communities that determine invasibility have generated much theory about the role of species diversity (Levine, 2000), fluctuating resources (Davis et al., 2000), habitat heterogeneity (Melbourne et al., 2007) and propagule pressure (Williamson, 1996), as well as a multitude of empirical tests of these hypotheses. The importance of any or all of these mechanisms may shift with the spatial scale of analysis and over time as invasions unfold (Strayer et al., 2006).

Our understanding of invasion patterns, and particularly processes, in the marine realm has lagged far behind the terrestrial world, even though invaders occur in virtually all marine ecoregions (Molnar et al., 2008). Like their terrestrial counterparts, most marine invaders tend to occupy low trophic levels (Fig. 1; see also Byrnes et al., 2007). Accordingly, evidence for some of the above mechanisms of community invasibility exists for invasions of seagrass, algal and sessile invertebrate assemblages, which essentially function like terrestrial plant communities and are strongly influenced by competitive interactions (Callaway and Walker, 1997). Marine invaders, in particular vertebrates, occupying higher trophic levels are much rarer (Fig. 1) but they present interesting cases to test current hypotheses because of their potential to be involved in predatory interactions which, in the sea, are affected strongly by the relative body sizes of predators and prey (Kerr and Dickie, 2001) and are an important force structuring marine communities (Hixon, 1991; Jennings et al., 2001).

One such invasion by predatory fishes has recently unfolded in the western Atlantic at a rate and magnitude never before documented in any marine system. It involves two species of Indo-Pacific lionfish (*Pterois volitans* and *P. miles*; Fig. 2). In their native ranges, *P. miles* occurs in the Indian Ocean from South Africa to the Red Sea and east to Sumatra, while *P. volitans* is distributed throughout the western Pacific from southern Japan to Western Australia and east to the Pitcairn Group in the South Pacific (Kulbicki et al., 2012; Schultz, 1986). Although genetically distinct (Kochzius et al., 2003), these sister species are difficult to tell apart visually (Freshwater et al., 2009). First documented off Florida in the 1980s, lionfish are now established as invasive species along the eastern coast of the USA, the Gulf of Mexico and the Caribbean Sea (Schofield, 2009), and rapid increases in abundance on many reefs have followed their swift range expansion (Green et al., 2012; Green and Côté, 2009). Lionfish consume a wide range of native fish and invertebrate species (Côté et al., 2013; Morris and Akins, 2009; Muñoz et al., 2011), and are well defended from predation by venomous fin spines (Halstead et al., 1955). The potentially extreme ecological impacts of this invasion (Albins and Hixon, 2011) provide an urgent impetus to understand patterns and underpinning processes associated with invasive marine predators.

As a result of this pressing need for information, the original trickle of research on lionfish, which for many years focussed mainly on venomology (e.g., Halstead et al., 1955; Saunders and Taylor, 1959) and mechanics of suction feeding (e.g., Muller and Osse, 1984), has been transformed into a torrent of new data on ecology, behaviour, and genetics, particularly from populations in the invaded range (Fig. 3). It therefore seems timely to take stock of this newly accumulated knowledge to examine how this information is contributing to the management of the lionfish invasion and to general understanding of invasions by predatory fishes. With this in mind, we conducted a review of the literature on lionfish in April 2013. We searched the Web of Knowledge™ with the keywords *Pterois* AND (*miles* or *volitans*), as well as Google Scholar with the keywords *Pterois* and "lionfish invasion", to retrieve all

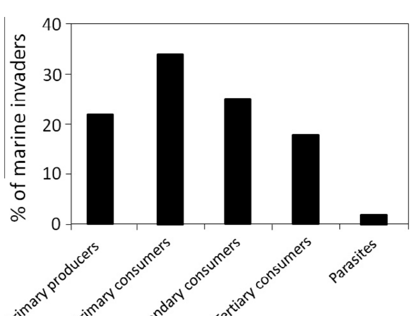


**Fig. 1.** Percentage of marine invading species in relation to trophic group. Data were derived from the Global Marine Invasive Species Assessment database (http://conserveonline.org/workspaces/global.invasive.assessment), which contained 334 species at the time of the review. We assigned each species to the highest trophic group given for that species.

**Fig. 2.** Invasive Indo-Pacific lionfish in the Atlantic. The photograph was taken off New Providence Island, Bahamas, in July 2010 (photo credit: I.M. Côté).