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Introduced macroalgae – A growing concern

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Abstract

Introductions of non-indigenous species to new ecosystems are one of the major threats to biodiversity, ecosystem functions and services. Globally, species introductions may lead to biotic homogenisation, in synergy with other anthropogenic disturbances such as climate change and coastal pollution. Successful marine introductions depend on (1) presence of a transport vector, uptake of propagules and journey survival of the species; (2) suitable environmental conditions in the receiving habitat; and (3) biological traits of the invader to facilitate establishment. Knowledge has improved of the distribution, biology and ecology of high profile seaweed invaders, e.g. *Caulerpa taxifolia*, *Codium fragile* ssp. *tomentosoides*, *Sargassum muticum*, and *Undaria pinnatifida*. Limited, regional information is available for less conspicuous species. The mechanisms of seaweed introductions are little understood as research on introduced seaweeds has been mostly reactive, following discoveries of introductions. Sources of introductions mostly cannot be determined with certainty apart from those directly associated with aquaculture activities and few studies have addressed the sometimes serious ecological and economic impacts of seaweed introductions. Future research needs to elucidate the invasion process, interactions between invaders, and impacts of introductions to support prevention and management of seaweed introductions.

Introduction

Introduced species are considered to be one of the greatest threats to native marine biodiversity and resource values of the world's oceans (Norse, 1993; Vitousek et al., 1997; Carlton, 2000). Regional studies have identified hundreds of non-indigenous marine species (NIMS) introduced through human activities. These studies are, however, limited to a few countries or regions, i.e. Australia, Europe, New Zealand and the United States (e.g. Pollard & Hutchings, 1990; Cohen & Carlton, 1995; Cranfield et al., 1998; Coles et al., 1999; Ruiz et al., 2000; Hewitt et al., 2004). There is very little information on the status of NIMS in other regions (e.g. Williamson et al., 2002 for 20 member economies of the Asia-Pacific Economic Cooperation, APEC). The rate of introductions of NIMS has increased in the last 20 years, reflecting increased global trade but also more survey effort (Ruiz et al., 2000; Ribera Siguan, 2002; Hewitt, 2003a). Some NIMS have had catastrophic effects on the recipient ecosystem, e.g. the Asian clam (*Potamocorbula amurensis*) in San Francisco Bay (Nichols et al., 1994) and the comb jelly (*Mnemiopsis leidyi*) in the Black Sea (Kideys, 2002). The combined effects of global change and species introductions are believed to result in biotic homogenization (e.g., Olden et al., 2004; Olden and Poff, 2004; Wilkinson, 2004). Widespread generalists and opportunistic species will dominate ecosystems, a pattern already observed in locations affected by environmental

Table 1. Number of non-indigenous marine species (NIMS) introduced to various regions.

Location	Total extant NIMS	Macroalgal NIMS (no.)	Macroalgal NIMS (%.)	Reference
French Atlantic Coast	104	21	20	Goulletquer et al. (2002)
Italy	110	32	29	Occhipinti Ambrogi (2002)
North Sea coast	82	20	24	Reise et al. (2002)
Chile	32	12	38	Castilla et al. (in press)
Hawaii	89	21	24	Coles et al. (1999), Godwin (2001) and Smith et al. (2002)
New Zealand	109	19	17	Cranfield et al. (1998)
Port Phillip Bay, Australia	99	16	16	Hewitt et al. (2004)
United States (continental)	298	24	8	Ruiz et al. (2000)

degradation, and likely to be amplified by species introductions (McKinney & Lockwood, 1999).

Marine macroalgae are a significant component of introduced NIMS (Table 1). These include several high profile species that have caused significant ecological and economic impacts (e.g. *Caulerpa taxifolia* (Vahl) C. Agardh, *Codium fragile* (Suringar) Hariot ssp. *tomentosoides* (Van Goor) Silva, *Sargassum muticum* (Yendo) Fensholt and *Undaria pinnatifida* (Harvey) Suringar; e.g. Trowbridge, 1998; Boudouresque & Verlaque, 2002; Ribera Siguan, 2002, 2003; Wallentinus, 2002; Occhipinti-Ambrogi & Savini, 2003). Macroalgae are considered to be especially worrying NIMS as they may alter both ecosystem structure and function by monopolizing space, developing into ecosystem engineers, changing foodwebs, and spreading beyond their initial point of introduction through efficient dispersal capacities (Thresher, 2000).

The majority (80%) of marine macroalgal orders contain introduced species: 7 out of 9 orders in the phylum Chlorophyta, 16 out of 19 orders in the Rhodophyta, 8 out of 12 orders in the Phaeophyceae. The numbers of introduced species per order are highly correlated with total species number (Figure 1, Pearson-Product moment correlation: $r^2 = 0.91$, $p < 0.05$). However, some orders contain more, others less, introduced species than expected by chance alone; for example the Ectocarpales, Laminariales and Bonnemaisoniales have more, while the Chaetophorales, Fucales and Corallinales have less introduced species than expected (Smith et al., unpublished data).

Recent reviews of the status of introduced marine plants, both with a regional and global scope, include current inventories of introduced species as well as assessments of introduction vectors and mechanism that may influence invasion success (Wallentinus, 1999a, 2002; Verlaque, 2001; Ribera Siguan, 2002, 2003; Smith et al., 2002). Despite recent research, especially in the Pacific region and the Mediterranean Sea, we still have a limited understanding of the invasion process, the distribution and ecology of less conspicuous introduced macroalgae, and the ecological and economic impacts of marine invasions. In this review we will update current knowledge of seaweed introductions using recent case studies to illustrate the three main phases of the invasion process: uptake and transport, release and establishment, and spread and impact.

Uptake and transport

The first stage in the invasion process depends on the presence of a transport vector and the availability of suitable macroalgal life stages for uptake by this vector. The most important pathways for the transport of NIMS are associated with shipping vectors (ballast water and fouling of hulls), aquaculture and the aquarium trade (Ruiz et al., 2000; Carlton, 2001; Hewitt et al., 2004). It is often difficult to pinpoint a pathway for a specific introduction; it may differ between regions or the introduction may have occurred through multiple pathways.

Fouling of ships' hulls, structures or other surfaces and living epibiotically (e.g., on mollusks) or as boring organisms (e.g., the conchocelis phase of Porphyra species boring into mollusk shells) are considered to be the most important pathways for the unintentional introduction of macroalgae (Ribera Siguan, 2003). All macroalgae have the potential to colonise ships' hulls and other maritime structures, especially species that occur either within or in close proximity to port environments. In Port Phillip Bay, Australia, fouling of ships' hulls is considered to be the most