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Restocking the sea cucumber *Holothuria scabra*: Sizing no-take zones through individual-based movement modelling

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Abstract

The valuable sea cucumber *Holothuria scabra*, known as 'sandfish', has potential for restocking. However, there is little information available to determine the size of the no-take zones (NTZs) needed to protect the released animals so that they can form nucleus breeding populations. To do this, we measured short-term movement paths of released juvenile (1–105 g) and wild adult (130–690 g) sandfish in a seagrass bed in New Caledonia. We then developed an individual-based model (IBM) to predict long-term dispersal of sandfish released as juveniles (1–16 g) at 1 individual m^{-2} within a 1-ha area, drawing on distributions of speed and directionality and the relationship between speed and animal weight from field data. Movement was non-random at the sampling scale used, since animals tended to turn <90° at each 2-h time step. We examined high- and low-growth scenarios by applying 50% and 25% of the modelled growth rates of sandfish held in earthen ponds (where they are known to grow faster). The dispersal of released sandfish was predicted to be limited in the first 2 years, then markedly faster thereafter. After 10 years, 6–12% of surviving animals were predicted to remain in the original 1-ha release site. To protect surviving sandfish as nucleus breeding populations for 10 years, and accepting 10% spillover, square NTZs would need to be 19–40 ha. The findings are useful for the management of restocking and pre-defining the size of sites for recapture surveys. Our model allows user-specified values for future releases and should be applicable for other sedentary marine invertebrates where basic data on movement and growth are available.

Keywords: Dispersal; Fisheries management; Invertebrate; Marine protected areas; Stock enhancement

1. Introduction

1.1. Restocking: the need for no-take zones

Appropriate management of released animals is crucial for restocking programmes (Bell et al., 2005). In conjunction with other forms of management, restocking (i.e., the release of hatchery-produced juveniles to restore breeding populations) could speed up the recovery of a fishery under certain circumstances (Bell, 2004; Bell et al., 2005). But there are fundamental tenets of restocking that underpin the success of stock restoration. These tenets are: (1) corrective management to mitigate the reasons why over-fishing or environmental damage occurred in the past; (2) protection of released animals to form an effective breeding population; (3) survival of sufficient numbers of released animals to sexual maturity and effective reproduction; (4) placement of released animals to allow recruitment of their offspring to other areas of suitable habitat, i.e., to act as a "source" population and (5) successful settlement and survival of progeny to maturity to rebuild a population that can sustain regular harvests. Here, we address tenet #3 for a tropical sea cucumber; i.e., how to protect the released animals from fishing so that they are able to reproduce successfully.

Restocking is often a costly exercise and the survival of released juveniles is often low (Bell, 2004). For many invertebrates, 'depensation', also called 'Allee' effects, cause reproductive success to drop below a certain parental population size (Caddy and Defeo, 2003). Invertebrate restocking should thus aim to restore relatively dense, discrete, breeding populations. In practice, unless the entire fishery is closed, hatchery-produced juveniles will often need to be released into marine reserves, or explicitly "no-take zones" (NTZs), to safeguard their eventual role as breeders. Under prudent

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non-spatial management regulations, such as size limits and quotas, some of the offspring in the open areas will eventually be fished. This is the delivery output of restocking for fishing communities.

No-take zones are a special class of marine protected area (Lubchenco et al., 2003; Sale et al., 2005) and fitting for the management of invertebrate restocking. They can exclude fishing only of the restocked species and have a defined duration (Kelleher, 1999). The duration of NTZs may be finite, e.g., 5–10 years, and based on the life-span of the species or the time needed to restore stocks to predetermined levels (Bell and Nash, 2004; Bell et al., 2005).

When establishing NTZs for restocking, the first questions concern where they should be sited, the fraction of the coastline to be covered, and how big they need to be (Botsford et al., 2003; Lubchenco et al., 2003). Although there are exceptions, Halpern (2003) showed that the biological effects of NTZs generally do not increase proportionally with reserve size. Very large NTZs are more difficult to gazette (i.e., obtain legislative approval) due to greater potential for conflicts of interest and will have high costs in greater surveillance, and displacing stakeholder use, particularly for the rural poor (Polunin, 2002). On the other hand, NTZs that are too small will allow too many animals to "spillover" across the zone boundaries, where they can be fished before they have spawned. Because the main aim of restocking is larval export, it is critical to know how big NTZs need to be to protect breeding animals.

1.2. Restocking sea cucumbers

Sea cucumbers (P: Echinodermata; C: Holothuroidea) are an economically valuable, yet generally depleted, fisheries resource (Battaglene and Bell, 1999; Conand, 2001). For some tropical Pacific nations, sea cucumbers are the most economically important non-finfish marine resource (Battaglene and Bell, 2004; Bell et al., 2005). They are easily harvested and stocks often recover very slowly, or not at all, from unchecked fishing pressure (e.g., Uthicke et al., 2004). The most valued of tropical species, the 'sandfish' *Holothuria scabra*, has been intensively exploited throughout its distribution from east Africa to the central Pacific (Hamel et al., 2001). Sandfish populations have limited gene flow, at the scale of tens of kilometres (Uthicke and Benzie, 2001; Uthicke and Purcell, 2004), so the recovery of over-fished populations is likely to be localised near release sites. The sandfish is a sedentary inhabitant of inshore fringing reefs and seagrass flats, feeding on detrital matter in sandy mud habitats (Mercier et al., 1999; Hamel et al., 2001). Sandfish reach sexual maturity between 180 and 330 g in weight (Shelley, unpublished; Conand, 1990, 1993), and are believed to live for around 10 years (Hamel et al., 2001).

Better management of sea cucumber fisheries is now being implemented but reproductive stocks of sandfish in many regions are too low to permit significant recruitment within an acceptable timeframe (Battaglene and Bell, 2004). The sandfish has good potential for restocking (Battaglene and Bell, 1999, 2004; Purcell, 2004) and methods for culturing juveniles are well developed (Battaglene, 1999; Pitt and Duy, 2004). However, information is critically lacking on: strategies for releasing hatchery-produced juveniles to optimise their survival to maturity; the spatial designs and scale of releases and management of the resulting breeding populations (Purcell, 2004).

Deciding the size of NTZs for restocking requires knowledge of the movement patterns of fishery species (Sale et al., 2005), but mark-recapture studies on sea cucumbers are lacking because the animals readily shed physical tags (Hamel et al., 2001; Battaglene and Bell, 2004). Alternatively, short-term movements can be measured in the field and used to model their dispersal over timeframes relevant to the restocking objectives. Indeed, much of the literature on the design of marine reserves is based on models, due to the paucity of empirical experience (Botsford et al., 2003). Modelling the required size of NTZs thus requires information on growth rates, size and speed of movements and dispersal simulations of released animals over many years. Sandfish are slow movers and reach sexual maturity at around 2 years of age in the wild (Hamel et al., 2001), although this time can be much shorter in rich earthen ponds (Pitt and Duy, 2004). Here we model the dispersal of *H. scabra* from release sites from measured movement paths of juveniles and adults in seagrass beds in New Caledonia under two growth scenarios. From this model, we provide predictions of the required sizes of NTZs to protect sandfish from fishing.

2. Materials and methods

2.1. Collection of field data

Data on movement patterns of sandfish were collected from shallow (0.2–3 m) seagrass beds in a sheltered bay at Ouano, New Caledonia (165.8°E, 21.8°S). The site is bordered by mangroves and the substratum is fine sandy mud, with a predominant grain size class by weight of 63–125 μm (upper 5 cm of sediments, $n = 8$). The seagrass cover ranged from 50% to 90%, dominated by *Cymodocea serrulata*, *C. rotundata*, *Halodule univervis* and *Syringodium isoetifolium*.

Wild sandfish adults (12–23 cm in length; 130–690 g) were located on 6 days (2 days, 1 week apart, in each the months of January, April and August, 2004), between 13:00 and 17:00 h. The study days provided a range of water temperatures and tidal fluxes. Individual sea cucumbers were identified by inserting a stake tied to a numbered surface float into the sediment next to each animal.

Sandfish juveniles produced at the WorldFish Center hatchery at Saint Vincent, New Caledonia, were grown to 1–105 g (2–12 cm length) in earthen ponds. These were released in July 2004 at the same field site and later marked with stakes in August, in the same manner as described above.