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Enhancement of an underexploited fishery – Improving the yield and colour of roe in the sea urchin *Centrostephanus rodgersii* by reducing density or transplanting individuals

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ABSTRACT

A large proportion of the sea urchin *Centrostephanus rodgersii* resource in New South Wales is unfished because of the unmarketable condition (i.e. yield and colour) of its roe. This unfished proportion of the population occurs in Barrens habitat, where urchin densities and grazing pressure limits development of the algal assemblage, their primary source of food. Using field experiments at different spatial and temporal scales, we investigated how the yield and colour of roe can be improved by increasing the urchins' access to food, either by reducing densities in Barrens or by transplanting individuals to other habitats. Significant improvements in both colour and yield occurred after reductions in density over short periods of time (i.e. 3 months), and greater improvement was observed after two years. Significant increases in yield occurred where density was reduced by as little as 33%, but the greatest significant increase to yield (i.e. >2 times) occurred where density was reduced by 66%. Urchins transplanted to habitat with an abundance of macro-algae showed significant improvements in colour and yield of roe after six weeks, although the magnitude of change depended on density and season. Although improvements to the condition of sea urchin roe over one year did not reach the levels observed in the normal commercial harvest from productive habitats, the enhanced roe from transplanted urchins was marketable and the operation was considered profitable. Given the results of the experiments were reasonably consistent at different spatial scales it is considered that *C. rodgersii* could be commercially harvested in generally unfished Barrens areas with the aid of density reductions or transplanting.

1. Introduction

Fisheries for sea urchins rely heavily on the marketable condition of the sea urchins' roe. Within wild populations of sea urchins, it is common for the yield and colour of roe to be variable, and so many individuals have roe that is not of a condition preferred by commercial markets (Agatsuma, 1999; Blount and Worthington, 2002; James and Heath, 2008). This variability in roe condition affects fishing effort, concentrating it in areas where fishers expect the condition of roe among individual sea urchins to be most consistent (e.g. Miller and Nolan, 2008). In some sea urchin fisheries, concentrations of fishing effort have led to serial depletion and worldwide production of roe has been declining since 1995 (Andrew et al., 2002; Agatsuma, 2013).

The condition, and consequent market value, of sea urchin roe is related to many factors but its size and colour are particularly important (Kato and Schroeter, 1985). Studies of sea urchins held in aquaria have shown that the amount and quality of food strongly influences the size and colour of roe (e.g. Vadas, 1977; de Jong-Westman et al., 1995; Wahle and Peckham, 1999; James and Heath, 2008; Phillips et al., 2009; Azad et al., 2011; Zhao et al., 2015) and when the amount and quality of food is increased, sea urchins are able to rapidly allocate resources to roe production (e.g. Levitan, 1991; Russell 1998; Guillou and Lumingas, 1999; Guillou et al., 2000; Cyrus et al., 2014). Variation in the size and colour of roe observed in wild populations has also been shown to be related to the availability of food (Meidel and Schiebling, 1998; Miller and Nolan, 2008). These studies suggest that the size and colour of roe in wild populations could be rapidly enhanced, if the availability of food was increased.

When sea urchin densities become high, there can be greater competition for limited food (Steneck, 2013), resulting in areas

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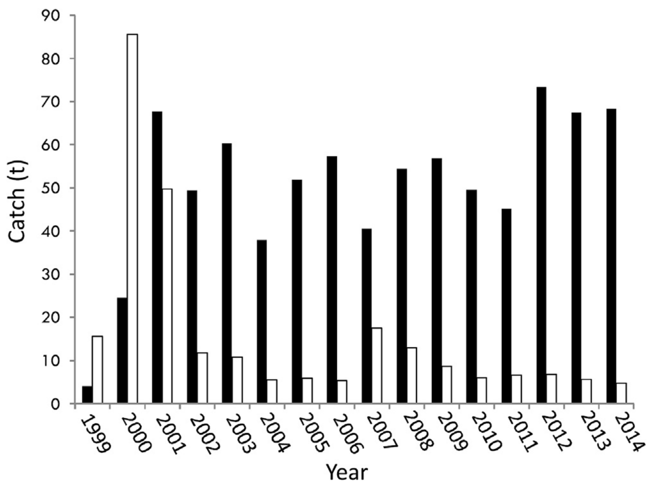

Fig. 1. Catch history of sea urchins in NSW since 1999; *C. rodgersii* (closed bar), *H. tuberculata* (open bar). Catches of *H. erythrogramma* are not given but did not exceed more than 1 t in any year. NB: Total catch prior to 1999 was 11.8 t.

becoming free of filamentous or foliose algae. These areas, known as Barrens, occur throughout the world (e.g. Underwood et al., 1991; Steneck, 2013). As food supply is often limited in Barrens, it is likely that the roe of resident sea urchins could be enhanced if competition for food was reduced. This could be achieved by: (1) reducing the density of individuals, thereby increasing the availability of food to those that remain; (2) transplanting individuals to areas where food was more available; or, (3) bringing food into Barrens.

In New South Wales (NSW), Australia, Barrens created and maintained by the purple sea urchin *Centrostephanus rodgersii* can represent >50% of the reef (Andrew and O'Neill, 2000). Worthington and Blount (2003) estimated the biomass of *C. rodgersii* in NSW to be 52,000 t, the majority being in Barrens. In NSW, fishers avoid catching individuals in Barrens because the size and colour of roe makes it unmarketable (Andrew et al., 1998) and fishing is done in habitats where macro-algae is abundant, particularly Fringe (*sensu* Underwood et al., 1991), which is characterised by an abundance and diversity of foliose algae. The roe of sea urchins residing in Fringe is generally of a marketable condition, being larger and of better colour than from the sea urchins in Barrens (Blount and Worthington, 2002; Byrne and Andrew, 2013).

There have been several attempts to develop the NSW Sea Urchin and Turban Shell (SUTS) Fishery over the last 30 years. While the fishery includes many other species, including red (*Heliocidaris tuberculata*) and white, or green, (*H. erythrogramma*) sea urchins, the most numerically dominant species in NSW is *C. rodgersii*. This is reflected in commercial catches which have been dominated by *C. rodgersii* since 2001 (Fig. 1). Difficulties with the reliable harvesting of good condition roe, and as a consequence, the costs of harvesting and processing sea urchins, have slowed the fishery's development. Annual catches in NSW have fluctuated around 50 t since 2000, despite Worthington and Blount (2003) indicating that sustainable catches of *C. rodgersii* of 200–1000 t could be possible. There are 37 endorsements in the NSW SUTS Fishery, although the majority of these are not active. Substantial capital investments in processing plants continue to be made in NSW, with aims of growing local and international markets to support increased harvests.

With an abundant population of *C. rodgersii* in Fringe there is currently little incentive to fishers in utilising the much larger population in Barrens. However, even at this early stage in the development of the fishery, anecdotal evidence suggests that some productive and more profitable areas of Fringe have had substantial reductions in the abundance of individuals with marketable roe. It is likely that techniques to enhance the roe of sea urchins in Barrens will be used more frequently as the fishery develops, as these areas are likely to reduce costs of fishing compared with productive areas further from processors. In addition, harvesting individuals from other habitats has great potential to reduce the pressure on sea urchin populations in Fringe, and would support increased sustainable catches.

In this paper we report on experiments aimed at improving the condition of roe of *C. rodgersii* by reducing the density in Barrens or transplanting individuals to Fringe habitat where food was more abundant. Experiments were designed to test whether results were consistent across various spatial scales and to determine the optimal timing of experiments. At the largest-scale, a commercial harvest and processing of sea urchins was done to demonstrate the potential commercial viability of methods to enhance sea urchin roe, in co-operation with industry.

2. Methods

2.1. Overview of approach

Experiments investigating the potential for roe enhancement by reducing density or transplanting sea urchins were done at three spatial scales and for various times. Experiments were first done at very small scales (i.e. metres), using cages, and for generally short periods of time. Treatments were then investigated at larger scales (100 s of metres) and for longer periods and then at a commercial scale, with the assistance of commercial fishers. In all investigations, urchins with a test diameter of 75–85 mm were used. Further, unless otherwise stated, the yield of roe in a replicate was a measure of the gonad weight as a proportion of the total weight of an individual. The colour of an individual's roe was matched against a standard colour chart and grouped into two categories, marketable or unmarketable, as determined on advice from commercial processors. Marketable roe consisted of bright yellow to orange colours, whilst unmarketable roe ranged from dark orange to brown. For analysis of colour, unless otherwise stated, replicates consisted of the proportion of individuals in a sample of sea urchins with roe that had marketable colour.

Potential differences in yields and the proportion of individuals with roe of a marketable colour were compared using analysis of variance. Homogeneity of variances was assessed using Cochran's test and data were transformed where necessary and is noted in associated tables.

2.2. Reductions in density

2.2.1. Small-scale experiment—Experiment 1

To assess the effect of reductions in density on the condition of roe, sea urchins were kept in small cages that had a basal area of 1.25 m^2 (1.12 cm × 1.12 cm). These were bolted to the reef haphazardly in flat areas of Barrens at a depth of ~7 m. The walls of cages were 10 cm high and made of Weldmesh® (galvanished steel, 0.4 mm gauge, 60 mm gap diameter), and the tops were covered with 1 mm wire mesh. Three replicate cages were built for each of three Treatments: absolute densities of 3, 6 and 9 sea urchins per cage, corresponding to reductions of natural density of sea urchins in the general area of Barrens by 66%, 33% and 0%. Treatments were assigned randomly to cages. Natural densities of sea urchins in the general area of Barrens were estimated by counting individuals in ten, randomly placed, 10 m × 1 m transects. The 0% density reduction was a control where sea urchins were handled and caged, to assess the effect of handling and caging with no change in density. In addition, a second control included a Treatment where sea urchins were Uncaged (i.e. undisturbed sea urchins without a cage), to assess whether the presence of a cage was potentially influenc-

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