Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

# Cadmium uptake and zinc-cadmium antagonism in Australian tropical rock oysters: Potential solutions for oyster aquaculture enterprises

Niels C. Munksgaard[a,*], Shannon Burchert[a,b], Mirjam Kaestli[a], Samantha J. Nowland[b], Wayne O'Connor[c], Karen S. Gibb[a]

[a] Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT 0909, Australia
[b] Aquaculture Unit, Department of Primary Industry and Resources, Northern Territory Government, Darwin, NT 0801, Australia
[c] NSW Department of Primary Industries, Port Stephens Fisheries Institute, Taylors Beach, NSW 2316, Australia

## ARTICLE INFO

*Keywords:*
Oysters
Aquaculture
Cadmium
Zinc
Antagonism
Phytoplankton
Northern Territory
Australia

## ABSTRACT

Variable and occasionally high concentrations of cadmium in wild oysters at a remote location with the potential to develop aquaculture enterprises motivated research into the distribution and sources of metals in oysters, seawater, sediment, suspended solids and phytoplankton.

*Saccostrea mytiloides* and *Saccostrea mordax* contained cadmium concentrations exceeding the food standard maximum level (ML) at three of four sites. At one site with high zinc levels in sediment, oyster cadmium levels were below the ML. Metal levels in seawater were not correlated with cadmium levels in oysters but high cadmium/zinc ratios were measured in *Trichodesmium erythraeum* blooms.

We suggest that oysters accumulate cadmium mainly from annual phytoplankton blooms except at sites where zinc availability is sufficiently high to prevent uptake though a mechanism of antagonistic exclusion. Knowledge of the source and uptake mechanisms of cadmium in oysters should lead to new management strategies to reduce cadmium levels in farmed oysters.

## 1. Introduction

Indigenous people consider low technology sea-based aquaculture as a culturally integrated form of work that aligns with customary practices on sea country in northern Australia (Fleming et al., 2015). Prior to westernisation, remote coastal communities were dependent on their sea country for subsistence (Smyth, 2004). This historical connection to seafood is still present in coastal communities today where there is a growing interest in aquaculture activities as income generating options. There are significant benefits to the establishment of aquaculture enterprises in Indigenous coastal communities as it supports community development and introduces a highly desirable industry to northern Australia.

Tropical edible oysters, such as Milky oysters (*Saccostrea mordax*) and Blacklip oysters (*Saccostrea mytiloides*), have been sporadically harvested from rocky foreshore areas in northern Queensland (Beattie, 2001; Nell, 2001) for decades, but recently interest in their culture potential has increased. Trial farming of tropical oysters has begun in Queensland and the Northern Territory and applications for culture of Blacklip oysters have been made in New South Wales. These developments have been underpinned by work done during the 1980s across the Asia-Pacific region, including Australia, on developing culture techniques for native tropical oyster species (see Coeroli et al., 1984; Southgate and Lee, 1998 for a review). In the Northern Territory, grow-out trials for Blacklip tropical oysters on both the Goulburn and Tiwi Islands (Northern Territory, Australia) are currently underway to identify the most suitable sites and management methods in collaboration with remote communities. Growth rates, survival and fouling of the shell vary between sites, indicating that some sites are more suitable than others for oyster farming based on production considerations.

Oysters extract suspended particles from the surrounding waters and, therefore may bio-accumulate pathogens and toxicants, including metals, from contaminated growing waters (e.g. Chan et al., 1999; Kruzynski, 2004; El-Gamal, 2011). To manage the risk to human health, oyster farmers must monitor a range of potential contaminants. The Australian Shellfish Quality Assurance Program (ASQAP, 2016) requires shellfish harvest areas to be classified based on a sanitary survey and the results of an ongoing water-sampling program. These classifications determine those areas from which oysters may be harvested and any conditions associated with harvest. Maximum permissible concentrations of high-risk chemicals are specified in the Food Standards

---

[*] Corresponding author.
*E-mail address:* niels.munksgaard@cdu.edu.au (N.C. Munksgaard).

http://dx.doi.org/10.1016/j.marpolbul.2017.09.031
Received 24 July 2017; Received in revised form 12 September 2017; Accepted 14 September 2017

Please cite this article as: Munksgaard, N.C., Marine Pollution Bulletin (2017), http://dx.doi.org/10.1016/j.marpolbul.2017.09.031

Australia and New Zealand Food Standards Code (FSANZ, 2016).

Because of its remoteness from major urban or industrial development, South Goulburn Island (SGI) is expected to present a near-pristine environment with a low risk of wild or farmed oysters exceeding the Maximum Levels (MLs) of the Food Standards Code. However, samples of oyster flesh from two sites off the Island in 2011 had concentrations of cadmium (Cd) above the ML of 2.0 mg/kg (wet weight). Other studies have shown similar results for oysters collected along remote parts of the northern Australian coastline (e.g. Peerzada et al., 1993). However not all sites recorded elevated levels and Peerzada et al. (1993) implicated the occurrence of phytoplankton as a potential source of elevated metals. The potential implications of these data for a future commercial enterprise necessitated a more detailed assessment of the occurrence of elevated metal concentrations in tropical edible oysters to identify possible management strategies to ensure the quality of oyster products.

In this study, we measured metal and arsenic (As) concentrations in oyster samples from four potential harvest sites at SGI over the wet and dry seasons. Our main objectives were (i) to compare metal and As levels to the FSANZ MLs and (ii) to assess associations between metals and As in oysters, seawater, sediment and suspended solids with a view to identify their possible sources. From a management perspective, knowledge of the sources of any elevated metals or As in oysters may aid the development of mitigative measures and here our comparisons of farmed and wild oysters are of value.

## 2. Materials and methods

### 2.1. Study site

South Goulburn Island is located 280 km northeast of Darwin and 3 km off the west Arnhem coast (Fig. 1) and has a tropical monsoonal climate with an annual average rainfall of 1137 mm falling mainly during November to April. The annual variations in seawater salinity and temperature are ≈28–36 and 24–31 °C, respectively. The only known discharge into the sea comes from a small sewage treatment plant near Warruwi and very few commercial industries operate in the region. Metal and metalloids in seawater and sediment are generally at near-pristine levels along the northern Australian coastline (Munksgaard and Parry, 2001, 2002).

### 2.2. Sampling

Three sampling sites (1–3) were previously selected as suitable sites for oyster growout trials as they offered relatively sheltered conditions and supported natural populations of oysters. Site 4 is more exposed to oceanic conditions. Site 3 is located adjacent to the town of Warruwi (population ≈ 500) while all other sites are distant from inhabited areas.

To investigate seasonal effects on metal content of oysters and seawater, samples were collected twice in the dry season (September 2012 and September 2013) and once in the wet season (February 2013). Wild Milky oysters and wild Blacklip oysters were collected at three sampling sub-sites (where possible) within each of the four sites around SGI. On average 10 specimens were collected of each oyster species at each site per trip but varied between sites based on availability. Blacklip oysters were less abundant than Milky oysters at all sites. Blacklip oysters were also deployed in the intertidal region (adjacent to wild Milky oysters) on an oyster long line in floating mesh bags (Zapco International Ltd.) in September 2012 at sites 1–3. They were then sampled twice (five and twelve months after deployment) for elemental analysis in the same manner as wild harvest oysters. The unopened oysters were placed in zip-lock plastic bags and placed on ice for transport to the laboratory.

Seawater for metals, chlorophyll-a and total suspended solids (TSS) analysis were collected adjacent to the oyster cages from a depth of ≈ 0.5 m during each sampling trip using acid-washed plastic bottles attached to a plastic bottle pole. During trip 3 a phytoplankton bloom occurred near sites 1 and 2 extending from the coastline to approx. 500 m offshore. Samples were skimmed off the surface layer for measurement of metal and arsenic (As) contents. The samples were fixed in Lugol's solution for phytoplankton identification and analysis.

Sediment was sampled at sites 1, 2 and 3 in 2016 to obtain representative samples of the < 20 μm grain size fraction. Samples were collected from intertidal flats adjacent to the oyster sampling sites. Nine samples of sediment were obtained from a 20 × 20 m area at each site at a consistent depth of 0–5 cm using an 80 mm diameter PVC ring. Four equal-sized sediment samples were taken at each of the 9 sub-sites, homogenised, stored in sealed plastic bags and frozen upon return to the laboratory.

In October 2015, Blacklip oysters originating from site 2 at SGI were

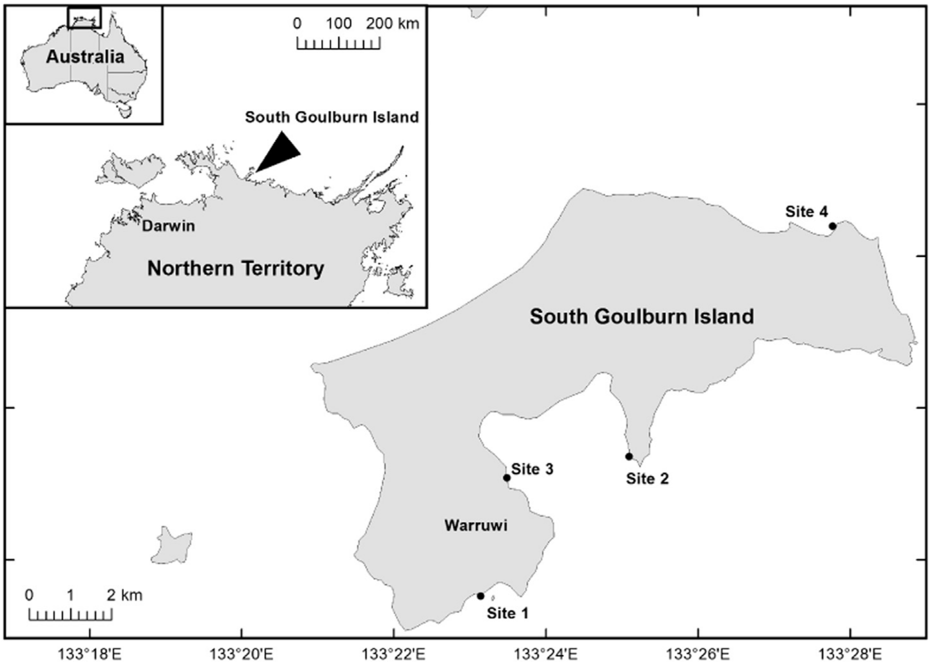

**Fig. 1.** South Goulburn Island, Northern Territory.