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Combined environmental stress from shrimp farm and dredging releases in a subtropical coastal lagoon (SE Gulf of California)

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ABSTRACT

Nutrient pollution causes environmental damages on aquatic ecosystems worldwide. Eutrophication produces impacts in coastal ecosystems, affecting biota and ecosystem services. The Urias coastal lagoon (SE Gulf of California) is a sub-tropical estuary under several environmental pressures such as nutrient inputs from shrimp farm effluents and dredging related to port operations, which can release substances accumulated in sediments. We assessed the water quality impacts caused by these activities and results showed that i) nitrogen was the limiting nutrient, ii) shrimp farm effluents increased particulate organic matter and chlorophyll a in the receiving stations, and iii) dredging activities increased nitrite and reduced dissolved oxygen concentrations. The co-occurrence of the shrimp farm releases and dredging activities was likely the cause of a negative synergistic effect on water quality which mainly decreases dissolved oxygen and increases nitrite concentrations. Coastal zone management should avoid the co-occurrence of these, and likely others, stressors in coastal ecosystems.

1. Introduction

Worldwide, coastal ecosystems provide ~38% of global ecosystem services such as nutrient cycling, waste treatment, biological control and habitat-refugia (Costanza et al., 1997). They allow the development of economic activities such as fisheries, commerce and recreational and cultural activities (Martínez et al., 2007). However, coastal ecosystems are subject to multiple environmental stressors due to human development (Crain et al., 2008). One of the main impacts is nutrient pollution, affecting more than 60% of coastal rivers and bays (Howarth et al., 2000), which have multiple natural and anthropogenic sources, such as urban and industrial waste, agriculture and aquaculture (Seitzinger et al., 2005). For example, aquaculture pond effluents are enriched in nutrients such as nitrogen (N) and phosphorous (P), organic matter and total suspended solids, affecting the water quality of the destination ecosystem (Biao et al., 2004; Costanzo et al., 2004; Mckinnon et al., 2002; Trott et al., 2004). The changes in nutrient availability have led to a variety of impacts, such as high levels of chlorophyll *a*, overgrowth of seaweed and epiphytes, anoxia and hypoxia events, and nuisance and toxic algal blooms (CENR, 2000; Devlin et al., 2011; Piñón-Gimate et al., 2009; Teichberg et al., 2009). If these effluents co-occur with other environmental stressors, such as dredging activities that resuspend pollutants trapped in the estuarine sediments (e.g. nutrients and organic matter), the impact could be aggravated (Essink, 1999; Lohrer and Wetz, 2003; Morgan et al., 2012; Stephens et al., 2001; Zhang et al., 2010, 2012).

Since 1985 there has been an expansion of shrimp aquaculture in Mexico, with the largest increase in the northwest region, with a total area dedicated to shrimp farming of 70,316 ha (Páez-Osuna et al., 2003). The environmental impacts of shrimp aquaculture vary depending on the siting and operation (size and intensity) of shrimp ponds. The deleterious effects of shrimp pond effluents on the water quality of the estuarine/lagoons depend on the magnitude of the discharge, the chemical composition of the shrimp pond effluents (e.g. organic matter and nutrients) and the characteristics of the receiving waters (e.g. volume, residence time and receiving water quality) (Páez-Osuna, 2001). The operation of one-ha shrimp pond discharges a mean of 110.2 kg of nitrogen and 37.5 kg of phosphorus per year (Páez-Osuna et al., 1999, 1997, 2013).

The Urias coastal lagoon (UCL) is the smallest coastal body of water in the SE Gulf of California. It is an urbanized system (with circa 380,000 inhabitants) that hosts a variety of installations including activities such as small scale fishing, petroleum and merchant fleet, various shipyards, seafood processing industries (flour and canned fish), shrimp aquaculture facilities and a thermoelectric power plant, which all together have contributed to pollution with nutrients and heavy metals

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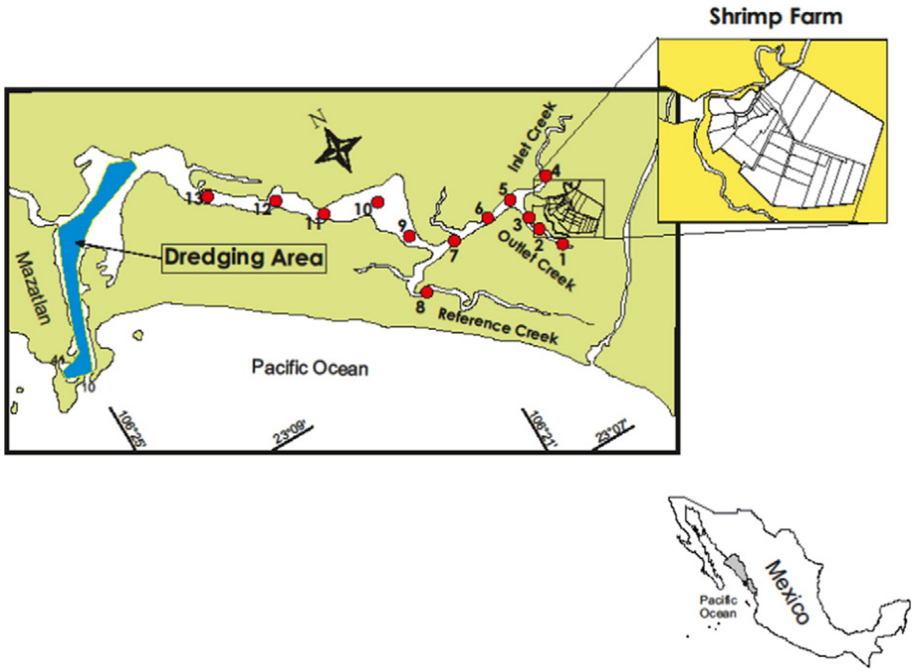

Fig. 1. Urias coastal lagoon dredging area (blue zone), shrimp farm and sampling stations (red circles). Sampled stations: outlet creek (OCr) 1, 2 and 3; inlet creek (ICr) 4; upper lagoon (ULa) 5, 6, and 7; reference creek (RCr) 8; intermediate lagoon (ILa) 9, 10, 11, 12 and 13.

(Cardoso-Mohedano et al., 2015b; Ferrando and Mendez, 2010; Osuna-López et al., 1986; Soto-Jiménez and Páez-Osuna, 2001). Also, the Mazatlan port requires regular dredging to maintain the access of large vessels. In the present work, we evaluate the combined effect of the releases from a shrimp farm and dredging on UCL water quality. Our working hypothesis is that the co-occurrence of these two stressors can produce a synergistic negative impact on the ecosystem water quality. This work shows the need to avoid the co-occurrence of multiple stressors in coastal ecosystems through effective coastal regulation and management.

2. Materials and methods

2.1. Study area

UCL (SE Gulf of California, 23°11′ N–106°22′ W) has a surface area of 18 km^2 and is 17 km long. Its circulation is tidally dominated with an average surface elevation range of 1.2 m, and maximum tidal velocity of ~0.6 m s^{-1} in the navigation channel (Montaño-Ley et al., 2008). The UCL does not receive a continuous fresh-water supply, thus causing anti-estuarine circulation (Cardoso-Mohedano et al., 2015a), and it has a salinity range of 25.8–38.4 ups (Páez-Osuna et al., 1990). The water body can be divided into three main areas, characterized by a vertically averaged speed of 0.91 m s^{-1} and a mean water age of ~15 days in the harbor area, 0.83 m s^{-1} and ~30 days in the intermediate area, and 0.31 m s^{-1} and ~70 days in the upper area (Cardoso-Mohedano et al., 2015a). In general, the water age is used to show pollutant accumulation zones and the connectivity of water bodies to the open sea (Kämpf et al., 2010; Cardoso-Mohedano et al., 2015a). It is calculated by using an aging term in the advection–diffusion equation and it is set to zero in a boundary (Delhez et al., 1999; England, 1995). The water age reaches steady-state when a balance between old water (far from the boundary) and the flux of younger water (close to the boundary) is attained. In water ecosystems with highly heterogeneous hydrodynamics, such as coastal lagoons, the "residence time" presents limited significance and the age tracer is considered to describe better the accumulation-dispersion pattern (Jouon et al., 2006).

In the UCL Upper area there is a well-preserved mangrove forest ecosystem of ~7.7 km^2 surface (Ruiz-Luna and Berlanga-Robles, 2003), whose main species are *Laguncularia racemosa* and *Avicennia germinans* (Villalba, 1989). The weather in the study area is warm humid (Awo(w)(e)) with a mean temperature of 25 °C (extreme values ranging from 7.5 °C to 39 °C; SMN, 2014) and summer rains (precipitation range of 700–1300 mm; INEGI, 2009).

2.2. Mazatlan port and dredging

The Mazatlan port provides services to commerce, tourism, fishing, seafood processing, naval industry and petroleum transportation (INEGI, 2013). The Mazatlan port is 2300 m long, 110 m wide and has a 12.20 m depth navigation channel, a 400 m turning basin and a 280,000 m^2 dock area. Due to the relatively high sedimentation rate in the zone, the port is subject to regular dredging activities (Fig. 1). In 2003 the dredging was carried out from August 1st to December 15th and produced a total dredging volume of 16,435,000 m^3.

2.3. The upper lagoon shrimp farm

The studied shrimp farm is located in upper lagoon (Fig. 1 and Supplementary material), near the mangrove forest, and has an area of 250 ha, divided into 57 ponds with 1–1.5 m average depth. The farm uses a semi-intensive culture system with 2 production cycles

Table 1
Urias coastal lagoon zones and sampling stations.

Zone	Stations	Hydrodynamic area[a]
Outlet creek (OCr)	1, 2 and 3	Upper area
Inlet creek (ICr)	4	Upper area
Upper lagoon (ULa)	5, 6, and 7	Upper area
Reference creek (RCr)	8	Intermediate area
Intermediate lagoon (ILa)	9, 10, 11, 12 and 13	Intermediate area

[a] Cardoso-Mohedano et al. (2015a).