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# Changes in the behavioural complexity of bottlenose dolphins along a gradient of anthropogenically-impacted environments in South Australian coastal waters: Implications for conservation and management strategies

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ABSTRACT

The susceptibility of bottlenose dolphins (*Tursiops* sp.) to disturbance within South Australian coastal waters is of particular importance due to both the ever increasing impact of anthropogenic activities on these waters and their semi-enclosed nature. Currently, little is known about the ecology of dolphins in this region, in particular in relation to anthropogenically-driven disturbances. This study investigates the level of stress experienced by bottlenose dolphins from the complexity of their temporal patterns of dive durations recorded along a gradient of environment types defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating. Dive durations were opportunistically recorded from land-based stations scattered across South Australian coastal waters both in the absence of boat traffic, and the potential for boat-related disturbance was investigated when a motorized vessel was within 100 m from a traveling individual to infer the effect of indirect exposure to boat disturbance. This approach fundamentally differs from more standard assessments of the behavioural effect of direct exposure to boat disturbance, for instance when dolphins chase fishing vessels, flee from motorboats or bow ride. Subsequent analyses were based on nearly 12,000 behavioural observations. No significant differences were found in dive durations measured in the absence of boats and when boats were present. In contrast, fractal analysis consistently identified significant differences in the complexity of dive duration patterns as a function of environment and exposure to disturbance. Specifically, bottlenose dolphins occurring in environments with less anthropogenic pressure exhibit a higher behavioural complexity. This complexity consistently and significantly decreases both within each environment and between environments with increasing anthropogenic pressure. These results further show that the relative changes in bottlenose dolphins' behavioural complexity increase in environments less impacted by anthropogenic activities. These results are discussed in the general context of the adaptive value of fractal behaviour, the susceptibility of bottlenose dolphins occurring in distinct environments to anthropogenic disturbance, and how behavioural properties identified with our fractal methods can be used to establish baseline information that can be used for the design and implementation of conservation and management strategies.


## 1. Introduction

The assessment of the nature and intensity of the interactions between anthropogenic activities and cetaceans has been the focus of considerable research effort over the last decade, essentially due to the extensive overlap of human activities with cetaceans in general and dolphins in particular (e.g. Nowacek et al., 2001; Lusseau, 2003a, 2005, 2006; Williams et al., 2006; Baş et al., 2015). Beyond the extreme cases related to propeller strike injuries, blunt trauma caused by vessel collisions and eventual subsequent death (Martinez and Stockin, 2013; Dwyer et al., 2014) and reports of fast boats disrupting dolphin behaviour and social life (Lusseau, 2005; Lemon et al., 2006), dolphins chasing fishing vessels (Jefferson, 2000), fleeing from motorboats (La Manna et al., 2013), and changing their acoustic behaviour to compensate for the masking noise in the presence of trawlers (La Manna et al., 2013), dolphins are exposed to numerous chronic anthropogenic stressors.

This situation is particularly important in coastal waters where dolphins are increasingly exposed to a variety of potential human disturbances (Kelly et al., 2004), and their consequences in terms of e.g. environmental contamination (Schwacke et al., 2002) and habitat degradation (Adams et al., 2008). These disturbances include commercial (Burdett and McFee, 2004) and recreational (Barco et al., 2010) fisheries, and the drastic increase in the occurrence of recreational motorized

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vessels (Buckstaff, 2006), recreational fishing (Powell and Wells, 2010), dolphin watching (Mustika et al., 2015) and swim-with-dolphin tourism (Peters et al., 2013). The understanding of dolphin responses to anthropogenic disturbance (e.g. the presence and type of boats and their related noise) is, however, not straightforward as a variety of sometimes conflicting responses have been reported. They include dolphins chasing fishing vessels (Jefferson, 2000) and fleeing from motorboats (La Manna et al., 2013), as well as a range of avoidance and anti-predator strategies such as increase in swimming speed, decrease in resting behaviour, directional changes, decreased inter-animal distance, increased breathing synchrony, and longer dive durations (Ribeiro et al., 2005; Lemon et al., 2006; Williams et al., 2006; Christiansen et al., 2013). Note, however, that the observed responses also depend on habitat, social context, physiological conditions and previous encounters with specific stressors (Lemon et al., 2006; Lusseau, 2003b, 2004; Sini et al., 2005). It is hence particularly difficult to disentangle the combined effects of disturbance and habitat on dolphin responses (Balmer et al., 2013; Pirotta et al., 2013), especially because it seems likely that dolphins tolerate chronic disturbance rather than flee from exposed areas (Bejder et al., 2009) given the plethora of anthropogenically-impacted coastal waters where dolphins are known residents.

Under chronic exposure to disturbance, dolphins have been shown to develop subtle behavioural responses, such as changes in activity budgets (Gill et al., 2001; Bejder et al., 2009) and the complexity of behavioural patterns (Seuront and Cribb, 2011). Specifically, a recent work conducted in a highly urbanized coastal environment, the Port Adelaide River-Barker Inlet Estuary (South Australia), showed that dive durations of the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) were not significantly affected by either boat presence or boat type (i.e. kayaks, inflatable motor boats, powerboats and fishing boats). In contrast, the complexity of the temporal dynamics of dive duration — quantified using fractal analysis and used as a proxy of stress, i.e. behavioural complexity decreases under stressful conditions; see MacIntosh (2014) and Seuront (2015) for reviews — was affected by boat presence and type (Seuront and Cribb, 2011). Specifically, the complexity of dive duration patterns did not significantly differ between control behavioural observations conducted in the absence of boat, and behavioural observations conducted in the presence of kayaks. A significant increase in behavioural stress was, however, induced by the presence of fishing boats, motorized inflatable boats and powerboats (Seuront and Cribb, 2011). These results suggest that standard behavioural metrics such as time allocated to different behavioural sequences, and the related statistical comparisons of mean duration or frequency may not be sensitive enough to detect subtle behavioural changes. In addition, the behavioural changes induced by a chronic exposure of dolphins inhabiting anthropogenically-impacted coastal areas to various boat disturbances may be much more difficult to detect than those related to the acute source of stress reported above; see also Seuront (2010, 2015) and MacIntosh (2014) for reviews on the value of fractal analysis to assess behavioural complexity and stress levels in a range of organisms. In addition, due to the semi-enclosed nature of South Australian coastal waters (Fig. 1), any anthropogenic impact to marine life may be considered as a conservation threat (Hoyt, 2005) as subsequent effects on the natural environment are likely to be particularly severe (Notarbartolo di Sciara and Birkun, 2002). In this context, the present work investigates how the fractal properties of dive duration patterns can be used to relate the behavioural complexity of *Tursiops* sp. to the nature of their habitat along a gradient of habitat types defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating.

## 2. Materials and methods

### 2.1. Study species

Two species of bottlenose dolphins, *Tursiops truncatus* and *T. aduncus*, have been recognised worldwide (Rice, 1998; Wang et al., 1999). Specifically, *T. truncatus* has a broad distribution and is found both inshore and offshore in cool temperate to tropical waters around the world (Leatherwood et al., 1983). In contrast, *T. aduncus* is only present in coastal and estuarine waters of the Indian and western Pacific Oceans, including south-eastern Australia (Rice, 1998; Wang et al., 1999). Both *T. truncatus* and *T. aduncus* occur in sympatry and parapatry (Wang et al., 1999; Hoelzel et al., 1998) and over a range of different habitats (Bearzi et al., 1997).

In South Australia, *T. aduncus* is found in coastal waters and gulfs (Kemper and Ling, 1991), in particular the Port Adelaide River-Barker Inlet Estuary, which supports a population of resident individuals (Cribb et al., 2008). Note, however, that recent genetic evidence, based on both mtDNA and microsatellite data, suggests that coastal bottlenose dolphins from South Australia, Victoria and Tasmania are evolutionarily distinct from *T. truncatus* and *T. aduncus* (Charlton et al., 2006). The former is likely to represent an undescribed dolphin taxon more closely related to the common bottlenose dolphins *T. truncatus* than to the Indo-Pacific bottlenose dolphin *T. aduncus* (Charlton et al., 2006). As a consequence, we refer to bottlenose dolphins as *Tursiops* sp. throughout thus study.

### 2.2. Study site

The complexity of breathing rhythms in *Tursiops* sp. was investigated from South Australian coastal waters exhibiting a gradient of environments defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating. Specifically, the identification of dolphin stress levels is particularly important in the Port Adelaide River-Barker Inlet Estuary (South Australia), where *Tursiops* sp. is a known resident (Kemper et al., 2008; Steiner and Bossley, 2008). This estuary, located on the north-eastern side of Gulf St. Vincent, is a sheltered, marine dominated estuary (Connolly, 1994) and is considered to have unique conservation significance and commercial value (Tanner et al., 2003). It is, however, in its southern part highly impacted by a number of anthropogenic activities ranging from sewage pollution, horticultural water runoff, recreational and commercial vessel traffic, dredging, urban development, habitat degradation and altered flow regimes (Edyvane, 1991, 1999; Connolly, 1994; Bryars, 2003; Seuront and Cribb, 2011). The recognition of the potential threats in this area therefore led to the declaration of the Adelaide Dolphin Sanctuary (ADS) in 2005, with the intent to protect and conserve both the dolphins and their environment. Although a declared sanctuary, little is still known about the potential links between the nature of their environment and the behaviour of dolphins in this area (Cribb et al., 2008).

To ensure the generality of our approach, our study investigated thirteen sites scattered in three distinct areas across South Australian coastal waters. These include the Adelaide Dolphin Sanctuary, the sandy beaches of the metropolitan coasts of Adelaide in St. Vincent Gulf, and Boston Bay in the Spencer Gulf (Fig. 1). Specifically, four sites were chosen inside the Adelaide Dolphin Sanctuary (ADS) along a gradient of increasing anthropogenic activities (Fig. 1C). These sites include the Angus Inlet at Garden Island, a relatively pristine sheltered water complex, fringed by mangrove forest, and dissected by numerous shallow bare sand channels (Fig. 2A), North Arm in the Barker Inlet which hosts a harbour for fishing, recreational and research vessels (Fig. 2B), Dock 2 (Port Adelaide) a cargo loading facility (Fig. 2C) and the highly urbanized Port Adelaide Inner Port (Fig. 2D). In addition, six sites located along the sandy beaches of the metropolitan coast of Adelaide in the St. Vincent Gulf (i.e. Semaphore, Grange, Henley, Glenelg, Brighton and Port Noarlunga; Fig. 1B,C) and in Boston Bay in the Spencer Gulf (Fig. 1D) were used as controls as they are much less impacted by anthropogenic activities. In contrast to the Adelaide Dolphin Sanctuary, the coastal waters of the Adelaide metropolitan area and Boston Bay are only impacted by both recreational non-motorized and motorized vessels and recreational fishing vessels.