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SOUTHERN HEMISPHERE FIN WHALE STOCK STRUCTURE: A SUMMARY OF PUBLISHED INFORMATION TO DATE

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ABSTRACT

Here we summarize available data pertaining to fin whale stock structuring around the Southern Hemisphere, suggest possible stock structure hypotheses and propose future work to improve understanding of the identity and differentiation of fin whale aggregations around the Southern Hemisphere.

BACKGROUND

Fin whales (*Balaenoptera physalus*) are globally distributed and are currently considered to comprise three sub-species, *B. physalus physalus* in the Northern Hemisphere, *B. physalus quoyi* and *B. physalus patachonica* in the Southern Hemisphere (Committee on Taxonomy 2017). *B. physalus patachonica* is a pygmy-type subspecies, located in low to mid latitudes in the Southern Hemisphere (Clarke 2004). Globally, *B. physalus* has been listed as endangered due to an estimated decline in abundance of over 70% from 1929 to 2007, which spanned three generations of the species. The decline was most intense in the Southern Hemisphere during the 20th century (Clapham and Baker 2002) where 726,462 whales are estimated to have been killed (Rocha et al. 2014) accounting for 83% of fin whale catches worldwide.

The current stock structure of the fin whale in the Southern Hemisphere is poorly described and mostly inferred from the distribution of historical catches. Southern Hemisphere fin whales are genetically distinct from those in the North Atlantic and Pacific oceans (Archer et al. 2013). However, phylogenetic analyses show that North Pacific and Southern Hemisphere clades are not reciprocally monophyletic (one North Pacific clade is placed among the Southern Hemisphere clades), and the Southern

Hemisphere clades investigated thus far represent fin whales from the southeast Atlantic and Indo-Pacific regions, with one sample included from the South Pacific (Archer et al. 2013).

It is generally thought that there is a hiatus in fin whale occurrence close to the equator, likely limiting the movements of fin whales between hemispheres (Mizroch et al. 2009; Edwards et al. 2015). However acoustic recording of the fin whale "pulse series" indicates seasonal occurrence at the equator in the Pacific (Stafford et al. 1999), with slightly lower detection numbers at a site ~8°N. In the Atlantic, three fin whales were caught off Brazil at Costinha (~7°S) during modern whaling (Zerbini et al. 1997). Genetic evidence to date suggests that cross-equator movements of females have been rare however (Archer et al. 2013).

Stock structure in the Northern Hemisphere has been described from using catch, distribution, acoustic and Discovery mark data and similar patterns may occur in the Southern Hemisphere. A review of fin whales in the North Pacific indicates that they have a broad mid- to high-latitude distribution in summer (down to ~35°N); in winter, this distribution shifts southwards to include low-latitude areas down to 23°N, but includes many detections of fin whales north of 40°N (see review by Mizroch et al. 2009). Distinct calving areas have not been discerned, but the region appears to comprise two distinct winter breeding areas off the coasts of Asia and America, and at least two non-migratory aggregations, one in the East China Sea and the other off the Gulf of California (Mizroch et al. 2009).

Here, we present data on the current knowledge of Southern Hemisphere fin whale distribution and population structure and suggest work to further describe Southern Hemisphere fin whale stock structure.

SUMMER DISTRIBUTION

Southern Hemisphere fin whale distribution is best known from summer feeding areas in the Southern Ocean, where they were intensively hunted during the 20th century. During the austral summer (abundance peak January/February) fin whales were sighted and caught primarily in the Southern Ocean (Clapham and Baker 2002; Edwards et al. 2015), but also sighted and caught in all months of the year in the waters off Chile and Peru (e.g. Clarke 1962; Allison 2016; Toro et al. 2016). Northern-central Chile is considered to be a summer feeding ground for some fin whales based on local presence and behaviour (Pérez et al. 2006) and restricted movements revealed by recent satellite tracking (Sepulveda et al. 2017).

Summer sightings elsewhere in the Southern Hemisphere are patchy; sightings have been reported from the Falkland Islands/Islas Malvinas in the southwest Atlantic (Frans and Augé 2016), from the Bonney Upwelling in south Australia (Gill et al. 2015) and, rarely, off South Africa (Findlay and Best 2016). Traditionally, fin whale feeding concentrations were assumed to correspond to Antarctic Areas I to VI (Brown 1962), although these divisions were primarily based on humpback whale catch concentrations (Donovan 1991). Inspection of Southern Ocean catch data (not including Soviet catches) corrected for catcher searching time may improve the resolution of catch densities, suggesting elevated densities at 40-65°W (roughly Area I/II), 30°W-20°E (roughly Area III), 40-70°E (roughly Area IV) and 140-160°E (roughly Area V) (de la Mare 2014). Including also Soviet illegal catch data (without correcting for catcher searching times) suggests that Area V fin whale concentration might span 140°E-170°W (Figure 1).

Figure 1. Apparent density of fin whales 1935 to 1941 based on catch/CSW (catch for a given amount of catcher searching time worked) using compound gamma estimates of handling time and search times. Copy of Figure 12 from de la Mare (de la Mare 2014)

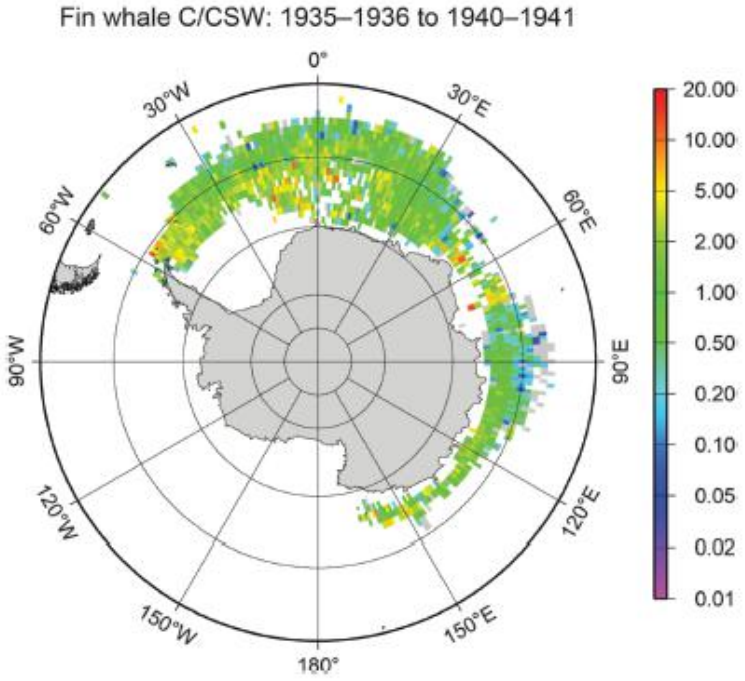
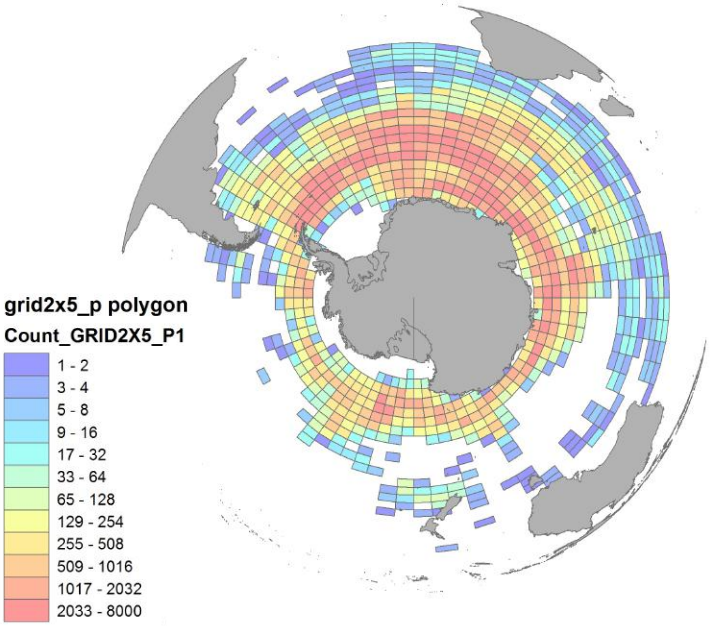


Figure 2. Total fin whale catches in the Southern Ocean 1900 to 1978, including illegal Soviet catches.



WINTER DISTRIBUTION

Winter distribution (August/September) is poorly understood. Acoustic analyses of the Southern Ocean in winter are absent of fin whale calls, suggesting that they are

elsewhere. Breeding is thought to occur offshore. Patchy sightings, catches and acoustic detections imply that fin whale breeding areas may be located in:

(I) **South-central and east Atlantic** waters, based on catches and sightings in the waters of South Africa, Namibia and Angola, up to ~6°S (Best 1994; Weir 2007; Findlay and Best 2016) and further offshore in the south-central Atlantic (Wheeler 1946).

(II) **Eastern Indo-Pacific** waters, based on winter acoustic detections off Fremantle, West Australia (Gedamke 2007).

(III) **Southwest Pacific** waters, based on winter acoustic detections off New Zealand (McDonald 2006), and in the Lau Basin between Tonga and Fiji ~20°S (Brodie and Dunn 2015).

(IV) **Eastern Pacific** waters offshore of Chile and Peru south of ~20°S (Acevedo et al. 2012). Some component of this population may be non-migratory (Toro et al. 2016) and has been hypothesized to include the pygmy fin whale *B. patachonica* (Clarke 2004). Unpublished fin whale calls off Juan Fernandez indicate the presence of fin whales there during winter across multiple years. Fin whales are regularly observed in northern Chile during winter but in much lower densities than in the summer months (Pacheco et al. 2015), and have been seen further offshore between Chile and Easter Island (75-88°W) at mid-latitudes (32-33°S) (Aguayo et al. 1998). Satellite tracking data support the idea that some whales are seasonally migratory (travelling south) while others forage locally (Sepulveda et al. 2017). This wintering area may also include the Galapágos Islands at the equator, where occasional austral winter fin whale sightings occur; austral winter sightings are more common than austral summer sightings, suggesting presence of Southern rather than Northern Hemisphere fin whales (Denkinger et al. 2013).

Sightings of fin whales off the coast of Brazil are uncommon, and catches were relatively rare during the whaling period; ~80 whales were caught in SE Brazil in the early 1960s (Andriolo et al. 2010). While fin whales are not regularly seen off Argentina (Reyes 2006), periodic strandings have been reported along the Argentinean coastline (Iñíguez pers comm, Bastida et al. 2007; Goodall et al. 2008) and some recent sightings have been made from the shore at San Jorge Gulf (Iñíguez pers comm).

POPULATION STRUCTURE

Global population structuring of fin whales was investigated by Archer *et al.* (2013) using whole mitochondrial genome sequences (mitogenomes). This study included 48 Southern Hemisphere fin whale samples collected primarily from high latitude southeast Atlantic waters (0-14°E, n=43), three samples collected in the high latitudes of the eastern Indo-Pacific at ~117°E, one stranding off West Australia and one sample from offshore in the southeast Pacific. The uneven geographical spread and small number of samples from areas other than the southeast Atlantic prohibits a statistically robust assessment of Southern Hemisphere fin whale population structure. No haplotypes were shared between regions, but nearly all Southern Hemisphere mitogenomes were unique (only 2 haplotypes were shared). A simple assessment of the genetic distances within and between regions using control region data from these samples (Table 1) does not show any indication that the eastern Indo-Pacific samples are more closely related to one another than they are to samples from the southeast Atlantic. However, similar patterns of lineage mixing across the Southern Hemisphere are seen for humpback whales, which are still found to be genetically differentiated

between breeding grounds and oceans based on mutational and frequency-based statistics (Rosenbaum et al. 2009; Jackson et al. 2014). Acoustic data show distinct call features for fin whales in East Antarctica (~70°E) compared to those near the west Antarctic Peninsula and Scotia Sea area (Širović et al. 2009). Unpublished analyses of fin whale calls off Juan Fernandez Island (Chile) indicates that these are also comparable to those detected off the west Antarctic Peninsula. Of 11 fin whales tagged off Chile during the whaling period, one was recaptured in Chilean waters (Clarke et al. 1978) and four in Antarctic Area II (South Atlantic), suggesting that some fin whales seasonally migrate between Chile and the high latitudes of the South Atlantic, including the western Antarctic Peninsula (Clarke 1962).

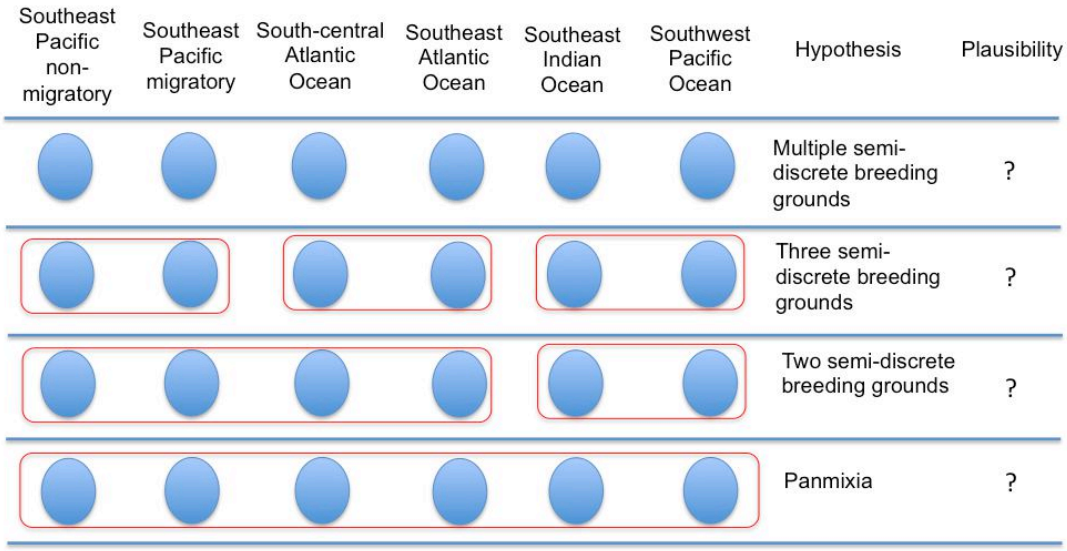
Control region sequence data are also available from Sremba *et al*. (2015) representing fin whales caught during 1900 to 1930 off South Georgia/Isla Georgias del Sur (southwest Atlantic). Given the above hypotheses regarding putative breeding grounds, these sequences might be anticipated to be most closely related to the n=43 southeast Atlantic samples (Archer et al. 2013); however these data represent the population prior to intense exploitation so would be anticipated to have different lineage content and frequency, complicating use of these to assess current population structure. Further genetic sampling across the Southern Hemisphere is required for a robust genetic assessment of population structure.

Table 1. HKY-corrected average pairwise distances between control region sequences using Archer *et al.* (2013) Southern Hemisphere fin whale dataset.

Total n=48	Southeast Atlantic n= 43	Eastern Indo-Pacific n=4	Southeast Pacific n=1
Southeast Atlantic n=43	0.024	0.025	0.025
Eastern Indo-Pacific n=4		0.023	0.028
Southeast Pacific n=1			NA

Table 2 provides a suggested framework and starting point for discussion of fin whale stock structure hypotheses and evaluation of plausibility of different stock structure scenarios. This is intended as a starting guide for data collection and analyses relevant for evaluating Southern Hemisphere fin whale stock structure.

Table 2. A set of hypotheses of putative fin whale population structures for evaluation, addition and discussion.



SUGGESTED WORK

Two overlapping strands of investigation are proposed to understand the population structure of Southern Hemisphere fin whales.

(1) An in-depth investigation into the hypothesis proposed by Clarke (2004) regarding the existence of a pygmy type fin whale which feeds at slightly lower latitudes than "Antarctic" fin whales. If *B. physalus quoyi* is in fact a mixture of two distinct forms, analyses of catch length statistics, acoustics and genetics are required to resolve this.

If these two forms do exist:

- Acoustic data may reveal differences in calls between the two forms (Gedamke 2009; Širović et al. 2009; Gedamke and Robinson 2010) and a comprehensive review of fin whale calls from Antarctica as well as lower latitudes is warranted.
- A focus on collecting genetic samples alongside good quality photo-ID (and ideally photogrammetry analysis of length), in order to co-identify individuals morphologically and genetically.
- A review of catch length statistics as proposed by Clarke (2004), particularly for catches taken at lower latitudes by the Japanese in the 1960s compared to earlier catches from the Antarctic.
- Isotope analyses of fin whales may also reveal trophic differences in feeding, which when examined in relation to genetics may allow discernment of any distinct forms.
- A global review of museum holdings of Southern Hemisphere bone/baleen and corresponding external morphs is required, including genetic sampling from the fin whale subspecies holotypes, particularly including *patachonica*.

(2) Build on the data collated in Appendix 2 of IWC (in press), to investigate the longitudinal differentiation among fin whale populations using strategic collection of skin biopsy samples for genetics and isotope analysis, satellite telemetry to discern seasonal movements, photo-ID to understand site fidelity and residency patterns and linkages between high and low latitude grounds.

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Figure 3. Hypothetical distribution of fin whale "breeding populations" and migratory connections in the Southern Hemisphere