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Assessment of humpback whale connectivity among African sub-stocks and movements among adjacent ocean basins

Introduction

Southern Hemisphere humpback whales (*Megaptera novaeangliae*) undertake annual migrations from the Southern Ocean summer feeding grounds to the warm tropical or sub-tropical winter breeding grounds (Chittleborough, 1965; Dawbin, 1956, 1966; Rasmussen *et al*., 2007). Within the region, seven Breeding Stocks (BSs) of the species are recognized by the International Whaling Commission (IWC) referred to as BSA to BSG, each associated with a specific breeding area (IWC, 1998). Based on genetic, mark-recapture or whaling data (Rosenbaum *et al*., 2009; Findlay, 2000; Fleming and Jackson, 2011), some BSs have been subdivided into sub-stocks. The breeding and feeding grounds used by each BS and sub-stock are as follows (see Figure 1):

- BSA: East coast of South America the south-western Atlantic Ocean; Antarctic: 50°W–20°W;
- BSB: West coast of Africa, being divided into B1 (Gabon) and B2 (western Namibia and South Africa); Antarctic: 20°W–10°E;
- BSC: East coast of Africa and the western Indian Ocean, divided into C1 (Mozambique), C2 (Comoros Archipelago), C3 (Madagascar), and C4 (Mascarene Islands); Antarctic: 10°E–60°E;
- BSD: West coast of Australia; Antarctic: 60°E–120°E;
- BSE: East coast of Australia and the western Pacific Ocean, split in E1 (Australia), E2 (New Caledonia), E3 (Tonga); Antarctic: 120°E–170°W;
- BSF: South-central Pacific Ocean, divided in F1 (Cook Islands) and F2 (French Polynesia); Antarctic: 170°W–110°W; and
- BSG: East coast of South America from northern Peru to Costa Rica; Antarctic: 110°W–50°W (IWC, 2007; Branch, 2011).

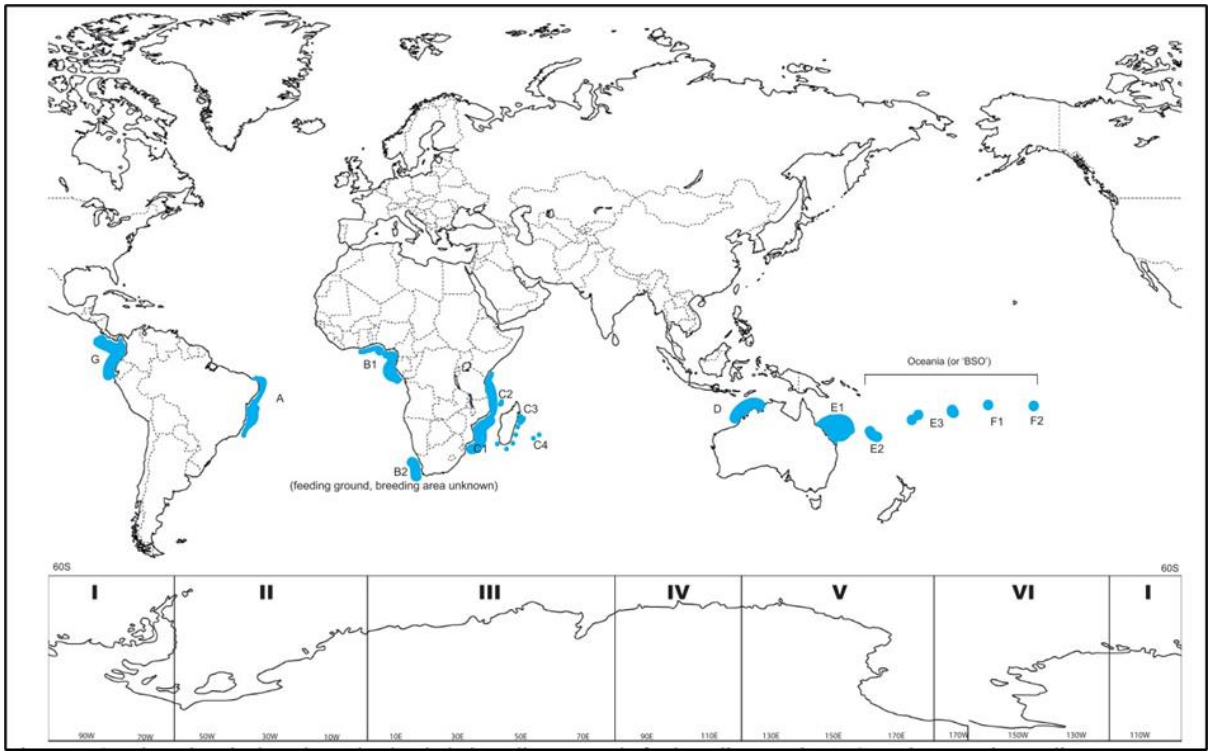

Figure 1.: The Southern Hemisphere humpback whale Breeding Stocks (A-G) and the Management Areas in the Southern Ocean, where their feeding grounds are located (Jackson *et al.*, 2015).

The species was severely depleted by modern commercial whaling in the Southern Hemisphere, with about 216,000 individuals killed across the region from 1903 to 1973 (Allison, 2020). As the species recovers from whaling (e.g., Jackson *et al.*, 2015), some BSs and sub-stocks are reoccupying areas used prior to whaling and/or expanding historical breeding grounds (e.g., Zerbini *et al.*, 2004; Irvine *et al.*, 2018; Horswill and Jackson, 2012), possibly affecting connectivity among BSs (e.g., Marcondes *et al.*, 2021).

For the southern African region, different levels of interchange have been identified amongst the sub-stocks that utilize the area. For example, there is photographic evidence of interchange between sub-stocks B1 and B2 (Barendse *et al.*, 2011), although genetic data have indicated differentiation between them (Pomilla *et al.*, 2006; Rosenbaum *et al.*, 2009; Carvalho *et al.*, 2014). Potential reasons for such genetic differentiation are maternal site fidelity, the use of two migratory routes (one coastal and the other offshore), and spatial or temporal segregation within the Gulf of Guinea breeding ground (Carvalho *et al.*, 2014). For BS-C, genetic studies have shown some level of differentiation between C1 and C3, and C1 and C2, but no differentiation between C2 and C3 (IWC, 2006; Pomilla *et al.*, 2006; Cerchio *et al.*, 2008; Rosenbaum *et al.*, 2009; Ersts *et al.*, 2011; Kershaw *et al.*, 2017). On the other hand, photographic and satellite tracking data suggest a significant mixing between sub-stocks C2 and C3, and between C3 and C4, but little interchange between sub-stock C1 and the other sub-stocks (Ersts *et al.*, 2006; Cerchio *et al.*, 2008; Dulau-Drouot *et al.*, 2011; Fossette *et al.*, 2014; Dulau *et al.*, 2017).

In general, photo-identification methods have been increasingly used over the past few decades to study whale population aspects such as abundance and movements between areas (e.g., Adams *et al.*, 2006). Especially the use of algorithms for automated photo-identification of individual humpback whales, such as the one used in Happywhale (Cheeseman *et al.*, 2022) has substantially increased the ability to track individual humpback whale movements across the globe. This is not only through the rapid and

automated identification of individual whales, but also due to the enhanced potential for contribution of opportunistic data through e.g., citizen science. As such, the considerable influx of new data into Happywhale has already shown evidence of substantial movement and mixing of individuals between the pre-defined BSs (Marcondes *et al*., 2021; Acevedo *et al*., 2022; Ramos *et al*., 2023) and revealed previously unknown movement patterns of individual humpback whales, indicating they may not be as segregated as previously thought, with substantial geographical overlap along the southern tip of Africa.

Aim

To gain a better understanding of the interchange between humpback whale BSs and sub-stocks, it is proposed to come together in a wide-ranging collaborative effort in which the use of automated photo-identification (through Happywhale) is optimised with the goal to progress towards the assessment of movement patterns and connectivity between, humpback whale BSs, with a special focus on BSB and BSC. Ultimately, the data would be used to produce estimates of population abundance and exchange rates, which will be relevant to the next IWC Southern hemisphere humpback whale in-depth assessment.

Proposed methods

To achieve this aim, we would like to invite individuals and organisations working in African sub stocks to contribute to this initiative by **uploading humpback whale photo-identification (fluke) images to the HappyWhale platform** with the goal to increase data availability for BS B and C.

On a broader scale, collaborations with researchers from BS A and BS D will also be developed to assess connectivity with adjacent breeding stocks.

Images submissions can be completed by individuals and organisations by creating an account and submitting data on the platform (https://happywhale.com), to ensure maintaining associated IP rights. New submitted images are automatically matched against all images available in HappyWhale and all possible matches are validated internally by the HappyWHale team before being included into the global catalogue (reference set). Each submitted image is scored by photo quality and distinctiveness. When a match is found, data contributors are informed via an automated e-mail. The results of the matches are visualised on a map on the HappyWhale platform and data can be exported for further mark-recaptures analysis.

Outcome

It is proposed the resulting matches will be assessed scientifically and written up in peer-reviewed publications. In this regard, we foresee this collaborative effort to be inclusive, and written MoUs can be established according to individual/institutional preferences if so required. It is envisioned that all data contributors would be joint co-authors in any publication arising from this collaborative effort.

Currently, 3 levels/type of analysis have been identified:

1. *Description of matches- Individual movements*

After the initial collation of photo-identification images in HappyWhale, the first outcome is envisioned to be a multi-coauthored manuscript, under the lead authorship of Alex Vogel (all other co-authors to

be listed according to contribution and/or in alphabetical order) which describes the long-distance movements of individually identified humpback whales from BSB and BSC with other BS.

The ambition is to have the manuscript ready for presentation at the next meeting of the IWC SC and that can be used to support a proposal for further mark-recapture analysis at the population level.

2. *Mark-recapture analysis - Population estimates*

Ultimately, multi-state mark-recapture analyses will be used to assess the rates of exchange among sub-stocks within BSB and BSC and between adjacent breeding stocks (BSs A-B-C-D) and obtain population size estimates for both stocks.

The timeframe for this analysis will be aligned with the agenda of the IWC Scientific committed, so that it is relevant to the next Southern Hemisphere humpback whale in-depth assessment.

3. *Movement between breeding and feeding grounds*.

The dataset will also be used to assess movement between breeding stock C and feeding grounds in Antarctica, provided enough data is available.

Current contributors

To date, several researchers or organisations from the region have been submitting their fluke images to HappyWhale, with multiple recaptures found between sub-stocks (Figure 1).

Breeding Stock B

- Gabon: WCS - Ocean Giants (Tim Collins)

Breeding Stock C

South Africa

- Seafari App, Cape Town, South Africa (Alexander Vogel)
- Mammal Research Institute Whale Unit, Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa (Elisa Seyboth, Ken Findlay, Els Vermeulen)

Tanzania

- Ekatarina Kalashikova
- WCS (Tim Collins)

Kenya

- Watamu MArine Association (Michael Mwango'mbe)
- WCS (Tim Collins)

Madagascar

- Cetamada (metadata to be updated) (Anjara Saloma)
- WCS (Antongil Bay)

La Reunion

- Globice (Vanessa Estrade, Violaine Dulau)

Other partners are collecting photo-identification data and might be willing to contribute.

Contributors to happyWhales from other BS and foraging grounds

BSA

- ***Brazil***

BSD

- **Western Australia**

Feeding ground/Antarctica

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