Network analysis by activity reveals community overlap and differences in centrality of individuals in Bottlenose Dolphins (Tursiops truncatus) in Cedar Key, Florida

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INTRODUCTION

• Bottlenose dolphins (*Tursiops truncatus*) are well known for their fission-fusion grouping patterns (Connor et al. 2000). This pattern is thought to represent the trade-off between the benefits of group living (protection from predators and social interactions) and food competition (Wrangham 1982, Gowans et al. 2008).

• Network analysis helps to clarify social complexities of animal groups. In a network, individuals are defined as “nodes” and the strength of their links to other individuals determines their relative position in the network.

• Many network analyses (Lusseau and Newman 2004, Wiszniewski et al. 2009, Augusto et al. 2011), focus on social behaviors or the population as a whole.

• Complex organisms cannot usually be defined by one network; individuals may associate more or less strongly, and with different individuals, depending on their behaviors (Gero et al. 2005).

• The purpose of this research is to examine and compare the networks of the bottlenose dolphin community structure in Cedar Key, Florida for 3 different behavioral states.

MATERIALS AND METHODS

• Using a combination of transects and surveys, we documented the distribution, group size, and behaviors of bottlenose dolphins off Cedar Key, Florida in 2008 and 2010. We used only individuals with 3 or more sightings.

• We produced separate networks (using Gephi) for each of the foraging, socializing and traveling behaviors and analyzed (using NetworkX and iGraph) each network for centrality measures, community structure and overlap. Edge thickness was adjusted by half weight indices (HWI) and node size by strength (sum of HWI).

• Associations were analyzed for each network using SOCPROG.

• We analyzed differences across the networks for distribution of centrality measures (Bonferroni-adjusted Mann-Whitney U pairwise test) and their values for individual dolphins (Bonferroni-adjusted Kendall’s Tau correlations).

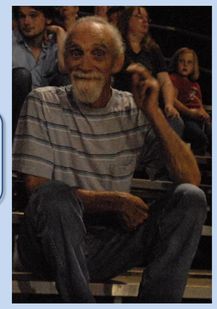
NETWORK TERMS

•**Clustering:** A measure of the likelihood that two associates of a node are associated themselves.
•**Strength:** The strength of the node is the sum of the half weight indices of its neighbors.
•**Degree:** The number of ties to other nodes in the network.
•**Closeness:** The extent to which an individual is near all other individuals in the network (directly or indirectly).
•**Betweenness:** The extent to which a node lies between other nodes in the network.
•**Eigenvector:** A measure of the importance of a node in the network.
(Whitehead 2008)

ACKNOWLEDGMENTS

We gratefully acknowledge our financial supporters: The National Geographic Society, The Explorers Club, and the American Society of Mammalogists.
This research was done in partnership with the International Fund for Animal Welfare.
All research was conducted under UMB IACUC 2009.115 and NMFS permit # 779-1633

In memory of Frank Cox: The ultimate citizen scientist



RESULTS

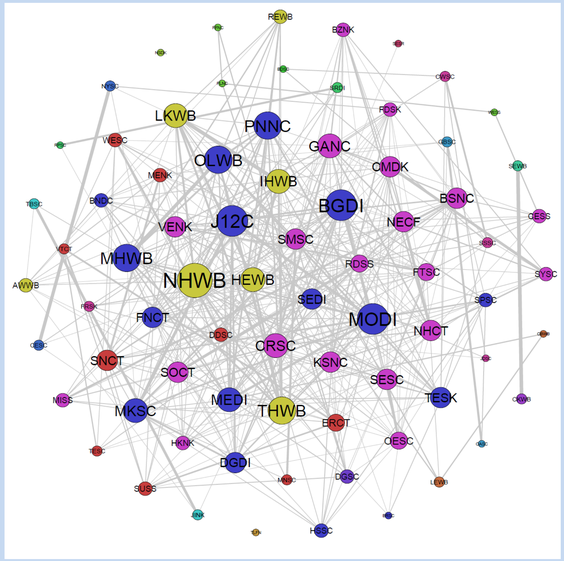


Figure 1: FORAGE network. Not significant for preferential associations (SOCPROG permutation test for preferred/avoided interactions, $p > 0.50$). There are 76 nodes (individuals), 462 edges (interactions between individuals), 18 communities and 4 connected components (islands, or unconnected groups) in this network.

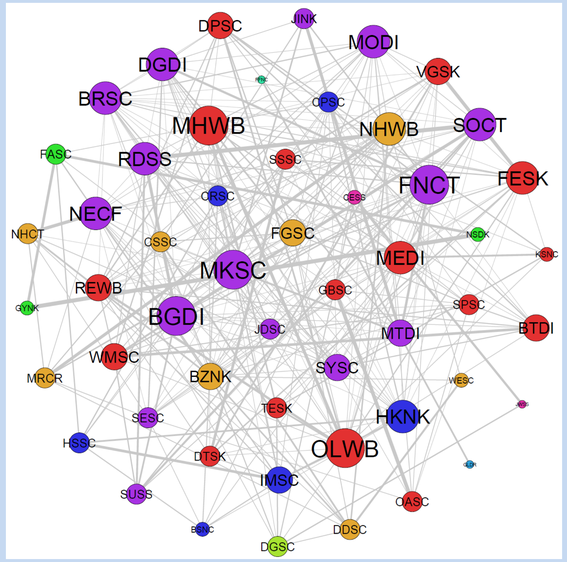


Figure 2: TRAVEL network. Significant for preferential associations (SOCPROG permutation test for preferred/avoided interactions, $p < 0.05$). There are 53 nodes, 302 edges, 9 communities and 2 connected components in this network.

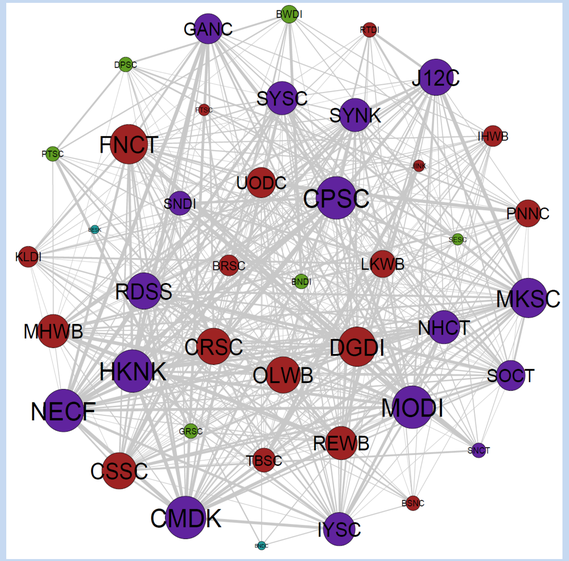


Figure 3: SOCIAL network. Significant for preferential associations (SOCPROG permutation test for preferred/avoided interactions, $p < 0.05$). There are 42 nodes, 458 edges, 4 communities, and 1 connected component in this network.

	Forage vs. Travel	Social vs. Travel	Forage vs. Social
Clustering	NS (Not Significant)	***p < 0.001***	***p < 0.001***
Strength	NS	***p < 0.001***	***p < 0.001***
Degree	NS	***p < 0.001***	***p < 0.001***
Closeness	***p < 0.001***	***p < 0.001***	***p < 0.001***
Betweenness	NS	NS	NS
Eigenvector	***p < 0.001***	NS	***p < 0.001***

Table 1: Significant differences in distributions of centrality values. Forage and Travel networks are the most similar in terms of their centrality measures, while Forage and Social are the most different.

	Forage vs. Travel	Social vs. Travel	Forage vs. Social
Clustering	NS	NS	NS
Strength	***p < 0.001***	NS	NS
Degree	***p = 0.002***	NS	NS
Closeness	***p < 0.001***	NS	NS
Betweenness	NS	NS	NS
Eigenvector	***p < 0.001***	NS	NS

Table 2: Correlation coefficients of centrality values between networks. Individuals’ centrality values in the network are the most similar between the Forage and Travel networks.

DISCUSSION

• The number of communities (groups of individuals who are highly interconnected) varies with activity network, with Forage having the most, followed by Travel, then Socialize, implying that the Socialize network is more closely knit than either Forage or Travel.

• The strength per node in the Social network is significantly different to that in Travel and Forage. Based on the diagrams, dolphins are connected more to the same individuals (have a higher HWI) when socializing than when traveling and foraging.

•There is significantly different clustering between Travel and Social, which, by examining the diagrams, may indicate that there are more tightly knit groups/preferences in Social activities than in Travel. Forage is not significantly different from Travel, implying that associations are not as strong in these two networks. This is also seen in the difference in connected components across the networks (1 for Social, 9 for Travel, and 18 for Forage).

• While betweenness has the same distribution across activities, the highly connected individuals in the Social network are not the same ones as in the Forage versus Travel network. This means that the role of individuals as links to other groups changes with behavior.

• The discrepancies in distributions and lack of correlation between the Social and Forage networks suggest that the two activities are completely separate associative states, and Travel may be an interim behavior where fission or fusion occurs. Gero et al. (2005) found that dolphins in Shark Bay, Australia, formed preferred associations in each behavioral state (and strongest in Social and Forage); this is not the case here.

• The strength per node in the Social network is significantly different to that in Travel and Forage. Based on the diagrams, dolphins are connected more to the same individuals (have a higher HWI) when socializing than when traveling and foraging.

• The Forage network has no significant preferential associations and is much more dispersed than the Social network, which is significant for preferential associations. Therefore we hypothesize that the dolphins in Cedar Key primarily utilize dispersed and irregularly distributed prey, which is not conducive for group foraging, and links in the foraging network are likely a function of the habitat. The group foraging driver-barrier behavior (Gazda et al. 2005) that previously was displayed in Cedar Key has all but disappeared.

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