Dolphin Social Network Analysis

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1 Introduction

The general field: biology

The analysis of social networks has identified properties that favour connection and information between members, a phenomenon mainly studied in human societies and on the Internet. In biology, this approach explores social behaviour, group dynamics and hierarchical structures between species.
Our project focuses on analysing the social network of bottlenose dolphins to discover emergent properties of this population. In social groups, decisions are influenced by the availability of hunted and intra-specific competition, which can lead to the formation of complex behaviours and social structures that facilitate decision-making, often requiring consensus among individuals in the group.

The specific application: ecology of social networks and animal behavior

We chose to analyse the social network of this species because we know that dolphins are social animals and tend to live in groups. This ties in with our study, which aims to examine the structure of their relationships, identify communities that may have been created within the population (including by gender), to determine their cohesion and identify interactions within the group.
Moreover, in recent times these animals have been subjected to various challenges, such as climate change and pollution: we want to analyse them as they help to keep the ecosystem in balance.

Figure 1: Bottlenose dolphins.

2 Problem and Motivation

Problem

Our project approaches the problem of understanding social interactions and network structure within a population of Doubtful Sound dolphins. In particular, we want to examine how these animals establish their social networks and how these structures influence their individual and collective behaviour.

Motivation

Theoretically, the analysis of this social network is fundamental to understanding the interactions and group cohesion of animals. This study provides important insights into the conservation and management of dolphin populations, supporting marine biodiversity and the sustainability of ocean ecosystems.
In practice, this information is crucial for identifying key communities and individuals whose well-being is essential for maintaining group stability and cohesion. Finally, the study provides insights into how dolphins tend to form groups, including by gender.

Main project contributions

Our project primarily contributes to understanding the social dynamics of dolphins in Doubtful Sound through detailed network analysis:

- **Social Network analysis**: in-depth analysis of how dolphins establish their connections, identifying key and peripheral nodes and emerging structures.
- **Individual and collective behaviour**: we examine how network structure influences individual and collective dolphin behaviour, providing new insights into social interaction mechanisms.
- **Behaviour of dolphins according to sex**: we study a subgraph of the main graph that possesses the characteristic of the sex of dolphins and that allows us to understand, also on the basis of this detail, how dolphins behave and make connections.

3 Datasets

The dataset used in this study was obtained from the site Networks: An Introduction, from which two publicly available files were downloaded on the site indicated above:

1. `dolphins.gml`: contains an undirected social network of the frequent associations between 62 dolphins in a community living in Doubtful Sound, New Zealand. The dataset was created by Mark Newman on 26 July 2006 and includes information on the 62 nodes (dolphins) and 159 edges (associations). Each node is identified by a unique ID and a label representing the name of the dolphin. The edges represent the connections between the dolphins, indicating the associations observed.

2. dolphins.txt: this file provides additional information on the dolphin network, including details on the properties and social roles within the network, as described in Lusseau's studies [1] [2].

To carry out further analysis and deepen the study on the network, we examined the study with the title "The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations" [3] and we found a graph showing the division between nodes containing male and female dolphins.
Studying the graph in Figure 4 on page 5 of the article, we extrapolated the gender information of the dolphins shown (that is 39). Then, we constructed a new txt-format file named "dolphins_sex" containing the name of each dolphin and the gender (male M or female F) alongside. The dataset created contains public information from the public article, but its creation is strictly private for our study.
Compared to the initial dataset that contained 62 dolphins with no indication of gender, this new file allowed us to perform a gender analysis taking into account only a portion of these dolphins (seeing as how the only information we were able to extrapolate from the scientific articles did not entirely comprise our network). Therefore, each extrapolated gender can be quantified as 22 male and 17 female dolphins.

3.1 Collection of data

The data were downloaded directly from the mentioned website and were not further digitised. The file dolphins.gml was used as the main format to represent the dolphin network, while dolphins.txt provided additional details and citations of reference studies. Regarding the file dolphins_sex.txt, as explained above, it was created manually using the visual information learned from the graph in the scientific reference document.

3.2 Tools used

To manage and manipulate the data, we used a public GitHub repository [4] as a tool for managing and storing project data. As IDE, we used Visual Studio Code software using Python as programming language and some of its libraries such as Pandas, NetworkX, Matplotlib and Plotly, Community and Defaultdict. We also made use of the Jupyter Notebook tool to manage the problem data, graphically display our networks and analyse the results obtained.

4 Validity and Reliability

How closely does the model of your dataset represent reality (validity)?

The validity of our network analysis study is quite good, as the data used came from actual observations of the bottlenose dolphin population in Fiordland, New Zealand.

[1] Lusseau, David. "The emergent properties of a dolphin social network." *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 270.suppl_2 (2003): S186-S188.

[2] Lusseau, David. "Evidence for social role in a dolphin social network." *Evolutionary Ecology*, 21 (2007): 357-366.

[3] David Lusseau et al., "The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations: can geographic isolation explain this unique trait?", *Behavioral Ecology and Sociobiology*, vol. 54, 2003, pp. 396-405.

[4] https://github.com/martinadaghia/Progetto_SNA

Our examined social network is based on real-life studies: interactions were retrieved from observations of the real ecosystem. This ensures that the data represent real-world dynamics and thus a true representation of reality.
However, one aspect that may not be 100% accurate concerns the network containing features on the sex of the dolphins: in this case, some nodes in the first dataset were not identified in the second, resulting in incomplete data on the sex of the dolphins.
Despite this, the available data still provide a solid basis for analysis. Therefore, to check the validity, we examined the reconstructed sub-network and found that it can be considered reliable for the following reasons:

1. We used our original network, which is considered reliable and well-studied, to reconstruct the edges and relationships between nodes in the sub-network. This approach allowed us to maintain the consistency and integrity of the relationships existing in the original network in the sub-network as well.

2. To evaluate the validity of the reconstructed sub-network, we compared the node centrality data between the main network and the subgraph. This comparison gave us a clear picture of how much the subnetwork structure reflected or diverged from the original network. Some measures revealed that some nodes maintain or slightly change their relative importance in the subgraph.

How does the way you treat the data affect the reproducibility of the study (reliability)?

The methodological approach we adopted in our study was designed to ensure maximum **reproducibility** and **reliability** of the results. This reliability is supported by several key factors:

1. **Standardisation of data management procedures.**
   - Use of standardised procedures for data collection, handling and analysis, with accurate documentation of each step in the process.
   - Development of well-documented analysis scripts that clearly outline the processing and interpretation of data, facilitating the repetition of the analysis by other researchers.

2. **Data management via GitHub.**
   - Use of a GitHub repository to manage all changes to data and analyses: this tool allowed us to transparently track each change and maintain a complete revision history.
   - Implementation of rigorous methodologies, detailed documentation and use of advanced data management tools (such as GitHub) to ensure the robustness and replicability of the study and consolidate the validity of the scientific conclusions.

3. **Data accessibility and reproducibility.**
   - As mentioned earlier, the datasets can be found easily via the links provided in Section 3. This transparency in the availability of data allows other researchers to examine the same information we used to conduct our analysis.
   - Moreover, the availability of original data makes it easier to reproduce analyses by third parties under similar conditions and verify the results obtained, further reinforcing the reliability of our methods.

5 Measures and Results

To guarantee the validity and reliability of our analyses, we analysed the structure of dolphin organisation and applied several network measures that allow us to better understand the social dynamics inside the Doubtful Sound dolphin community.
The graphs produced by our study are as follows:

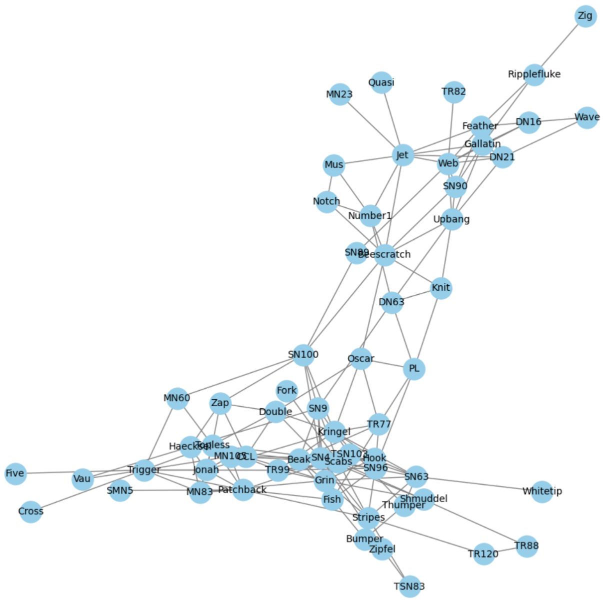

Figure 2: Dolphin network.

The social network of this dolphin community is defined by an indirect, non-bipartite, unweighted graph organised as follows:

- Nodes: representing the 62 dolphins,
- Edges: representing the links between the dolphins in this community. The edges are of the non-oriented type.

One of the simplest measures found is the **degree of each node**; in an undirected network, as in our case, the degree of a node is the number of edges connected to it. In our case, we have ordered the nodes from the highest to the lowest degree for clarity: the results obtained show that the dolphin with the highest degree has value 12, while that with the lowest degree 1.

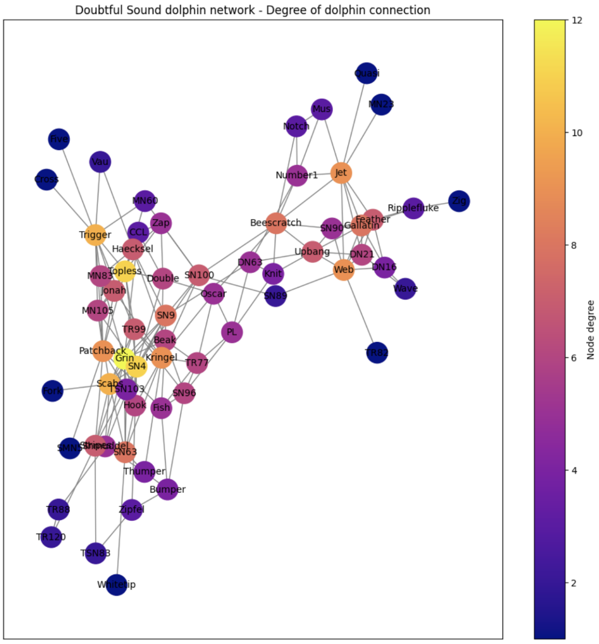

Figure 3: Graphical visualisation to show the degree of connection of the dolphins through shades of colour. As can be seen, the node with the highest degree of connection is Grin, that is the dolphin with the most connections, followed by SN4 and Topless with 11 connections, and so on until the dolphins with only one connection are shown in dark blue.

Our network consists of **a single connected component**, which therefore consists of the entire network where all the dolphins are connected to each other and we do not have isolated groups of nodes.
The average path length represents the average of the shortest distances between all pairs of dolphins in the network. This value indicates that, on average, approximately 3.36 edges must be crossed to move from one dolphin to another within the network.
The diameter of the network represents the maximum distance between all pairs of dolphins in the network. In this case, the value 8 indicates that the maximum distance between any two dolphins in the network is 8 edges.
Network density indicates the proportion of links present relative to the maximum possible number of links between nodes in the network. In our case, the density of 0.0841 indicates that about 8.41% of the possible links between dolphins are present in the network, highlighting the structure and cohesion of the dolphin community.

Main network subgraph with sex features

Before proceeding with the measures, let us briefly explain the structure of the subgraph of the main network. The file regarding the subgraph contains the names of the dolphins and the sex (M or F) for each of them.
The sexes are subdivided in the subgraph as follows:

- 22 male dolphins (M): `['Beak', 'DN21', 'DN63', 'Feather', 'Gallatin', 'Haecksel', 'Jet', 'Jonah', 'Knit', 'MN105', 'MN83', 'Notch', 'Oscar', 'Patchback', 'PL', 'Quasi', 'Ripplefluke', 'SN90', 'SN96', 'Topless', 'Upbang', 'Web'];`
- 17 female dolphins (F): `['DN16', 'Double', 'Fish', 'Five', 'Grin', 'Hook',`

’Kringel’, ’Scabs’, ’Shmuddel’, ’SN4’, ’SN63’, ’SN89’, ’Stripes’, ’TR88’, ’Trigger’, ’Wave’, ’Whitetip’].

The dolphin Notch is visibly distant in the figure 4 from the rest of the group, simply because the nodes it was connected to in the original graph (Mus, Number1, Beescratch) are not present in the subgraph.

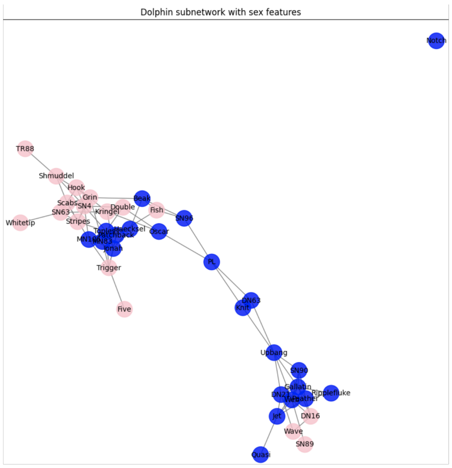

Figure 4: Graphic visualisation of the sub-network: female dolphins are shown in pink, and male dolphins in blue.

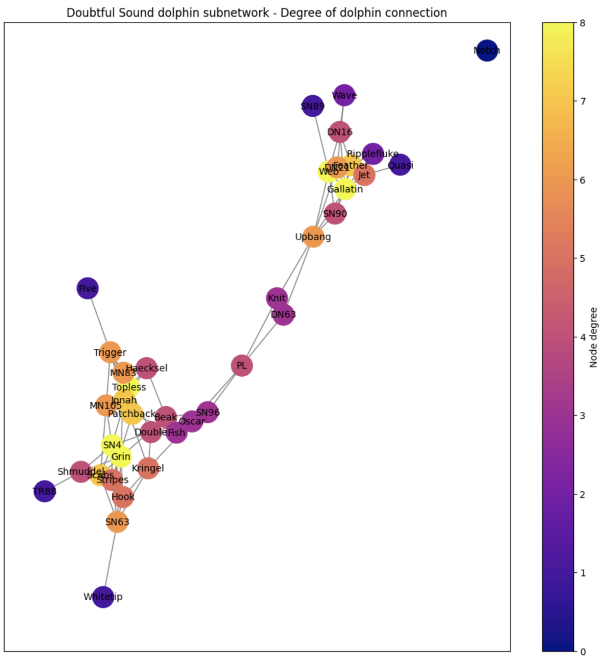

Figure 5: The figure shows which nodes have the highest degree of connectedness. The nodes Gallatin, Grin, SN4, Topless and Web have the highest value (8) coloured yellow..

Now, let us take a closer look at the **measures of centrality** used to define which dolphins are the most important and most central within the main graph community, comparing them with the results of the same measures for the subgraph.

5.1 Degree centrality

5.1.1 Original network

Let us analyse what degree centrality is in our case, i.e. with an undirected graph: the degree centrality of a node is simply the number of connections (edges) it has with other nodes.
In our case study, the nodes with the highest degree in our dolphin network are those that have the most connections with other dolphins. The nodes with the highest degree are more central in the network.
Nodes with higher degree centrality values, such as **Grin** (0.1967), **SN4** (0.1803) and **Topless** (0.1803), are probably the most central and potentially influential nodes in the dolphin network.
Nodes with lower centrality values, such as **SMN5** (0.0164), **TR82** (0.0164), **Whitetip** (0.0164) and **Zig** (0.0164), have few direct connections and can be considered peripheral nodes in the network.

5.1.2 Sub-graph constructed with sex feature

- The Gallatin, Grin, SN4, Topless and Web nodes have the same degree centrality in the subgraph (equal to 0.2105). From what was written earlier, we note that the Grin, SN4 and Topless nodes also maintain their importance in the subgraph.
- Other nodes with higher degree centrality in the subgraph, such as Feather, Jonah, Patchback and Scabs, are more central in the subgraph than the original network (with centrality of 0.1842).

Observations
There are few differences between the most central nodes of the original graph and those of the subgraph, which suggests that the main nodes for degree centrality remain more or less the same.
When we consider the sex of the dolphins, we note that many of the central nodes, such as Grin, SN4, and Topless, retain their importance. It is interesting to note that among the nodes with high degree centrality in the subgraph, most are male, with the exception of Grin, SN4, and Scabs, which are female. This might suggest that, in our network, male dolphins tend to have more direct connections than females, with the exception of a few central female nodes.

5.2 Betweenness centrality

5.2.1 Original network

Betweenness centrality is a fundamental measure in network theory that indicates how frequently a node is located on the shortest paths between other nodes. This measure is based on the concept that nodes located on many critical paths are strategically important for the flow of information within the network.
The nodes with the highest betweenness centrality are: **SN100**: 0.2482, **Beescratch** (0.2133), **SN9** (0.1431), **SN4** (0.1386), **DN63** (0.1182).
These nodes are located on a significant amount of minimal paths between other nodes, indicating a strategic position in the network. In particular, the SN100 node has the highest mediation centrality, suggesting that it is a key node for the overall connectivity of the network.
In contrast, nodes with zero centrality of intermediation, such as **SMN5**, **TR82**, **Whitetip**, and **Zig**, are not located on any minimum path between other nodes, indicating a marginal role in the network with regard to flow mediation.

In summary, in our network, nodes with high betweenness centrality are crucial for communication and information flow within the dolphin community.

5.2.2 Sub-graph constructed with sex feature

Comparing the betweenness centrality values between the original graph and the subgraph, interesting differences emerge that reflect the internal dynamics of the two networks.
The nodes with the highest difference in subgraph betweenness centrality between contexts are **PL** (0.4651) , **Upbang** (0.4074), **Oscar** (0.2745), **DN63** (0.2048), **Knit** (0.2048).
It is important to point out that the DN63 node was also influential in the original graph, so it does not lose its importance in the subgraph.

Observations
The reorganisation of relationships in the sub-network led to changes in the hierarchy of nodes as measured by betweenness centrality. The ability of some nodes to mediate communication between others has been reduced compared to the original graph, while others have gained importance in this role in the subgraph.
When we consider the sex of the dolphins, we note that the nodes with high betweenness centrality are male, with the exception of a few female nodes such as Grin and SN4, which, however, score low compared to the first positions held by males. Therefore, male nodes play a more significant role in mediating the flow of information.

5.3 Closeness centrality

5.3.1 Original network

Closeness centrality measures how close a node is to other nodes in the network, using the shortest paths. This metric is defined as the inverse of a node's average distance to all other nodes in the network. Nodes with high centrality of closeness values are able to reach other nodes quickly, suggesting a central location and direct access to information.
The nodes with the highest closeness centrality in our network are: **SN100** (0.4178), **SN9** (0.4040), **SN4** (0.3987), **Kringel** (0.3910), **Grin** (0.3765). These nodes have a lower average distance than other nodes, indicating that they can spread information more efficiently in the network.
Quite the opposite, nodes with the lowest closeness centrality, such as **TR82** (0.2328), **Ripplefluke** (0.2163), **Wave** (0.2133) and **Zig** (0.1784), are further apart on average from the other nodes, suggesting a less central role.

5.3.2 Sub-graph constructed with sex feature

The comparison of closeness centrality between the subgraph and the original graph shows interesting differences in the proximity and accessibility of nodes inside the two dolphin networks.
In the subgraph, nodes **PL** (0.3079) and **Oscar** (0.3053) show the highest values of closeness centrality. It could be said that they are more central (close in terms of path) to other community members and play a key role in the efficient transmission of information in the sub-network.
In addition, the presence of nodes such as Double, Kringel and SN96 (with closeness centrality of 0.2977) also indicates significant proximity and connectivity between members.

Observations
The distribution of closeness centrality shows significant variations between the original graph and the subgraph, with some nodes maintaining their centrality (such as Kringel) while others see large changes in their relative position. Thus, the reorganisation of the local network and relationships between nodes has led to a reduction in global accessibility for some nodes that have lost the ability to quickly reach other dolphins.
We observe that in addition to male dolphins, there are also a few females (despite being fewer in number than males) such as Double and Kringel who hold a high position in closeness centrality. This suggests that in the spread of information, females also play an important role compared to previous measures in which males predominated.

5.4 Eigenvector centrality

5.4.1 Original network

The eigenvector centrality is a measure that extends degree centrality by considering not only the number of connections of a node, but also the importance of the nodes to which it is connected. In other words, a node can achieve a high eigenvector centrality by having few very influential neighbours or many neighbours with modest centrality. This makes the measure particularly useful for identifying nodes that are central not only in terms of the number of connections, but also the quality of those connections.
From the results obtained, we note that nodes with the highest eigenvector centrality, such as **Grin** (0.3158), **SN4** (0.3006) and **Topless** (0.2850), are connected to nodes that are themselves highly central in the network. On the contrary, nodes such as **Zig** (0.0005), **TR82** (0.0024) and **MN23** (0.0024) have very low eigenvector centrality values, suggesting that they are connected to less influential nodes or have few valuable connections.

5.4.2 Sub-graph constructed with sex feature

The distribution of centrality changes significantly, with some nodes seeing an increase in their centrality while others decrease, suggesting a reorganisation of the network in the subgraph, for example:

- In the main network, the Grin node has the highest centrality. However, in the subgraph, Grin drops to fifth place: this suggests that it may have lost influence.
- In the first two positions of the sub-network we find **Topless** and **SN4**, which maintained a high position in both networks.
- The two nodes **MN105** and **Jonah**, which are more central in the subgraph with values of 0.2920 and 0.2892 respectively, are not in the main network.

Observations
The differences between the original graph and the sub-graph reflect how some nodes play a more central role in the efficient transfer of information than others according to the network.
Analysing the sex, in which case we note that there is an equal distribution between male and female dolphins: this indicates a balance between the two sexes and both play a significant role in influencing the network.

5.5 Load centrality

5.5.1 Original network

Load centrality is a measure that assesses the importance of a node based on the amount of flow passing through it. This type of centrality is useful for identifying nodes that play a crucial role in facilitating the flow of information and traffic inside the network. In other words, nodes with high load centrality are frequently found on paths connecting other nodes in the network.
The list shows that nodes with the highest load centrality, such as **SN100** (0.2401), **Beescratch** (0.1992) and **SN9** (0.1496), are crucial for the flow through the network, indicating them as key points for global connectivity. In contrast, nodes with zero load centrality, such as **SMN5**, **TR82**, **Whitetip** and **Zig**, do not facilitate the flow between other nodes, suggesting a marginal role in the network with regard to mediating the flow of information.

5.5.2 Sub-graph constructed with sex feature

In the subgraph, **PL** (0.4910), **Upbang** (0.4301) and **Oscar** (0.2815) show the highest values of load centrality. This could indicate that these nodes handle a large part of the information flow within the sub-network and guarantee efficient transmission and traffic management of information in the community.

Observations
The comparison of load centrality between the main network and the subgraph shows differences that reflect a reorganisation of the network, leading to a change in the flow of information and in the relations of the flow according to gender. The nodes that manage the flow of information have changed in the subgraph and, when analysing the gender of the most relevant dolphins in the sub-network, it can be seen that there is a male predominance although there are also females in important positions.
For the gender distribution among nodes with higher load centrality, we see that the dolphins with more significant values are male. This indicates a tendency for male nodes to handle more traffic in the network than female nodes.

5.6 Identification and analysis of communities in dolphin networks

5.6.1 Clustering coefficient

The clustering coefficient indicates the tendency of dolphins to form groups or communities. A high clustering coefficient means that neighbours of a node also tend to be close to each other, suggesting strong social cohesion.
The clustering coefficient of our network is low at 0.2590, indicating that it is not highly clustered. This could indicate that the relationships between dolphins are not extremely dense in terms of small, highly interconnected groups, but there are still some sub-structures.

5.6.2 Louvain algorithm and modularity

Using the Louvain algorithm, we identified different communities in the network. The division of the network into four communities indicates that there are four distinct groups in the dolphin population that have many internal connections but relatively few connections with other groups. Hypothetically, these groups could represent natural social subgroups, such as families, hunting groups or other social units.

Modularity indicates the quality of the division of the network into communities (found by the Louvain algorithm). In our network it is 0.5214 and is quite high, suggesting that the communities found (in our case four) are well defined.

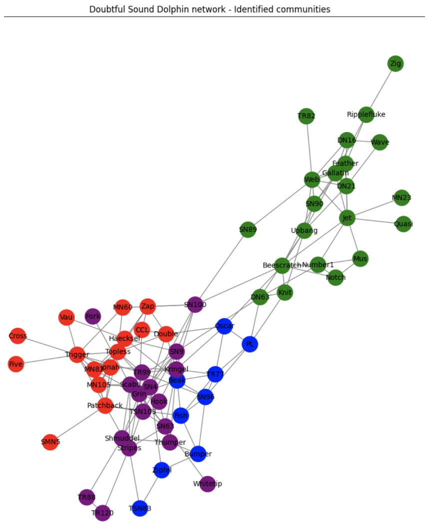

Figure 6: Representation of the four communities identified with the Louvain algorithm.

5.7 Groups of nodes

5.7.1 Clique

A clique in an undirected network is a set of nodes in which each node is directly connected to all other nodes in the group and may overlap with other different cliques. The presence of cliques usually indicates the presence of highly cohesive subgroups.
In our study of the dolphin network, there are different cliques that show a varying degree of overlap between them, indicating connectivity between groups rather than clear separation. From the results obtained, we note that the cliques in the network are close together (as can be seen from the figure 8), all have at least one node in common and are thus interconnected.

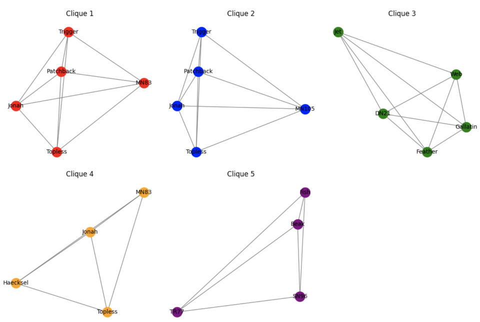

Figure 7: Representation of the 5-cliques identified in the dolphin network.

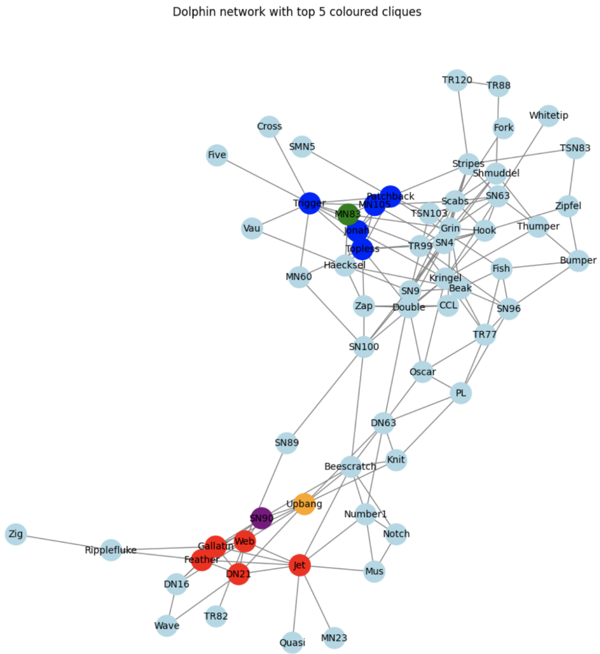

Figure 8: Dolphin network in which the nodes belonging to the 5-cliques are coloured as in the figure above. It can be seen that in some nodes the colours overlap, this is because they belong to more than one clique.

This feature may also explain why the network appears as one connected component. Although dolphins form distinct communities, the presence of shared nodes between cliques suggests a continuous relationship between groups rather than a clear division.

5.7.2 Core numbers and K-core

Core numbers

A core is a set of nodes connected in a network, where each node is connected to at least k other nodes in the set. It represents the level of density with which the node is connected to other nodes.

From the results, we know that dolphins with a core number of 4 are strongly integrated in the network and have numerous connections with other dolphins, while those with a value of 1 are the peripheral and less influential dolphins. We continue the k-core analysis using core numbers.

K-core

A k-core of a network is a subgraph in which each node is connected to at least k other nodes in the subgraph. By changing the value of k, you can examine how the connected structure of the network changes.

We only keep nodes that have a k=4 (highest possible value to take): nodes that have a lower k are not considered because they are peripheral nodes that have few connections with other nodes. This allowed us to find a subgroup of the dolphin network that is particularly well connected and cohesive. Every node in this subgroup has at least four connections, indicating a higher connection density than nodes with fewer connections.

The higher connectivity suggests that these dolphins have more frequent and perhaps more stable interactions with each other. Their removal could have a significant impact on the overall structure of the network, as they are connected to many other nodes.

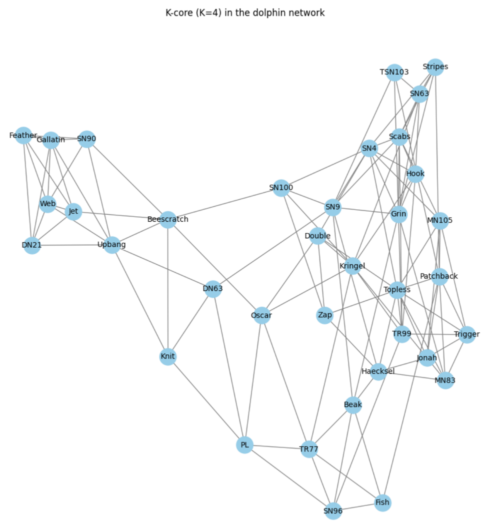

Figure 9: Sub-network of dolphins that have four connections with other dolphins.

5.8 Homophily

5.8.1 Original network

Homophily refers to the tendency of individuals to connect with others who are similar to them in some way. A positive value indicates assortativity, i.e. nodes with similar degrees tend to connect with each other, while a negative value indicates disassortativity, i.e. nodes with different degrees tend to connect with each other.
In our study, we have a **negative assortativity coefficient** (-0.0436) indicating a tendency towards disassortativity, i.e. high degree nodes tend to connect with low degree nodes.
This disassortativity could imply that in the dolphin network, very social dolphins (with many connections) also tend to connect with less social dolphins. From the results we can deduce that the more influential dolphins have a slight tendency to connect also with the more peripheral ones, thus strengthening the interconnections in the network. This could influence social dynamics such as the dissemination of information, the evolution of relationships between dolphins and the centrality of certain individuals in maintaining network cohesion.

5.8.2 Sub-graph constructed with sex feature

The **coefficient of assortativity per degree** in the subgraph of 0.0628 indicates a slight tendency for the network to form connections between nodes with similar degree levels.
Despite this slight tendency, dolphins interact in a balanced way, favouring a more even flow of information or influence in the network, rather than a concentration of power in a few nodes.
The **coefficient of assortativity by sex**, which has a higher value of 0.4570, indicates a marked tendency of dolphins in the subgraph to establish preferential connections with individuals of the same sex (preference between intra-sex interactions). This phenomenon may reflect specific social or behavioural dynamics where interactions are influenced by gender differences.

5.9 Triads

Triads are structural configurations of three nodes in a network. They are important in social network theory because they represent configurations of three nodes and can be indicative of more complex social structures such as clusters or communities. Analysing triads can provide insights into network cohesion and network resilience to disturbances.
In particular, our network contains a total of 570 triads that are represented by groups of three interconnected nodes. They are evenly distributed, with each specific triad repeated exactly six times, indicating how many times that particular combination of nodes occurs inside the network. This suggests that there may be some regularity or common structure inside the network.
The uniform repetition of the triads suggests a **homomomorphism degree of triads** (that is that different parts of the network have the same configuration of interconnections between nodes) and highlights **density** of connections inside the network.
In summary, the analysis of triads in the dolphin network shows a robust and cohesive social structure, with specific groups of dolphins playing key roles in the overall social structure.

6 Conclusion

Our study provided a in-depth analysis of the social network of bottlenose dolphins resident in Doubtful Sound, New Zealand. The quantitative analysis of network measures applied to the Doubtful Sound dolphin community provided important insights on the social structure and internal dynamics of this group. Furthermore, to confirm the validity, we compared the centrality data between the two networks to see how far the sub-network is from the latter. With the subgraph we have a clearer structure thanks to factors such as degree of connection and gender. The latter allowed us precisely to highlight more precise dynamics in terms of degree connections by highlighting specific gender-related social interactions.
The central dolphins of the network we have identified are Grin, SN4, and Topless, which are influential in both the original graph and the subgraph constructed considering the sex of the dolphins. Specifically, we noted the predominance of males, tending to be more important in the traffic of information than a few exceptions of relevant positions of some females.
We identified four distinct communities in the network, suggesting internal groups with strong connections. These communities may represent broader social groups taking into account the global view of the network.
Furthermore, we identified five small, densely connected, cohesive and overlapping groups, indicative of very strong and direct relationships (e.g. very close friendships): this suggests a solid cohesion of the structure of the entire network, despite the presence of these distinct groups.
We also found that the more social dolphins tend to interact with the less social ones, facilitating the dissemination of information and strengthening interconnections in the network. More specifically, dolphins tend to form connections with individuals of the same sex, reflecting social dynamics influenced by gender differences.
In conclusion, we can define the structure of dolphins as uniform and robust with solid connections even between different nodes, forming a single connected network.

7 Critique

Our analysis has deepened the social network of this population, allowing us to satisfy the problem we had previously set ourselves in the 2 section. However, the available data was minimal to carry out further in-depth analysis, and below are some of the critical points we identified:

- **Little information in the dataset**: due to the lack of detailed data on this social network, our study may not have caught all the nuances of this species.
  It would be interesting to have more details in order to better analyse the social interactions and to be able to observe the singular behaviour of individuals within the community according to, for example, sex (of all dolphins) and age.

- **Creating new factors not available to us**: the social dynamics of dolphins could vary greatly depending on various external factors, such as the season of the year and climate change. In addition, research could be carried out in the field over several separate years in order to produce a more accurate analysis, allowing any differences produced between years to be analysed.

- **Ecological role of dolphins**: we know that dolphins, in addition to being lively and playful animals, are crucial to protecting the marine ecosystem in our ocean waters. These animals help maintain the balance of the ecosystem: they control fish and calamari populations, keep numbers in check, and balance the impact of each species on the ecosystem. Future analyses should take these ecological aspects into account.

In conclusion, these critical issues represent ideas for improving field research with dolphins. This new research would allow us to obtain valuable information contributing to a broader study of animal social networks.