Space for Sustainability Award

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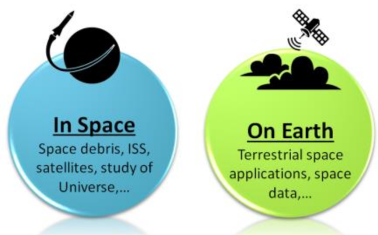

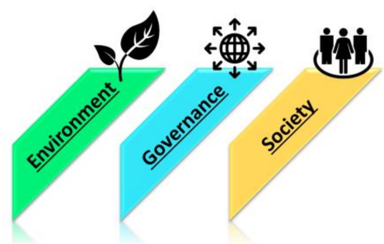

Forecasting Cetacean Strandings

This paper looks at the possible creation of an algorithm that would provide a forecast for cetacean strandings giving an approximation of the time and location, allowing for either the prevention or mitigation of the stranding event by allowing organisations to respond within a significantly reduced time-frame The algorithm would use live data feeds from sources such as the ESA Sentinel satellites and run this through a pre-determined set of conditions that would allow it to calculate the probability of strandings occurring for all coastlines. The provision of data and the need for a central governing body is also discussed.

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Key Words: *Forecasting, Cetacean Strandings, Factors, Algorithm*

1. Introduction

My proposal is for the development of an algorithm that can forecast cetacean stranding events, leading to the prevention or mitigation of these events through preparation and adequate warning. This paper focusses on identifying the underlying factors that contribute to stranding events, the analysis and provision of data, the development of the algorithm and, finally, the governance and implementation necessary to allow it to function effectively.

2. Influencing Factors

There are many factors that are thought to contribute towards cetacean strandings. Due to the lack of data surrounding cetacean strandings it's not known if these factors actually contribute to the events (Cordes, 1982). However, the following all exhibit a strong correlation with cetacean strandings and therefore are strong candidates for being considered as influencing factors.

2.1 Natural Factors

For the purposes of the algorithm, a natural stranding refers to accidental strandings in which the stranded cetacean is in full health and just requires help to re-float. Although strandings can also be due to cetacean illnesses, at present these cannot feasibly be mapped and therefore unfortunately cannot be included in the algorithm. This means that strandings caused by natural illnesses are unlikely to be forecast.

2.1.1 Topography

Gently sloping shorelines are thought to contribute towards cetacean strandings (Brabyn and McLean, 1992) particularly those with a protrusion out into the ocean such as is found at Cape Code, Massachusetts and Farewell Spit, New Zealand (Brabyn and McLean, 1992) (Mead, 1979) which are also areas that experience frequent mass strandings. It is theorised that gentle slopes can distort the cetaceans' ability to echo-locate, leading them to think there is open water where there is actually land. These areas can be thought of as 'acoustical dead-zones' for cetaceans (Sundaram 2006). Areas with gently sloping shorelines would automatically have a much higher probability of a stranding occurring in that location at any given time. This could therefore be maintained as a fixed higher probability value within the algorithm.

Data provision: For this factor, bathymetry data for around coastlines is required. Not currently widely available however the ESA are working on an 'International Satellite Derived Shallow Water Bathymetry Service[1]' in conjunction with Proteus Geo, which is set to launch in July 2017.

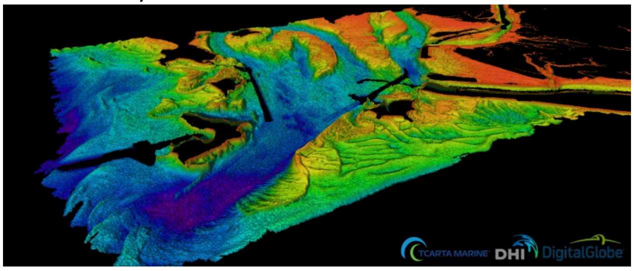

Figure 1: *Shallow Water Bathymetry in Abu Dhabi - Source: ESA*

This data could be used to identify areas that could present high stranding risks due to the topography of their shorelines.

2.1.2 Geomagnetic Anomalies

Cetaceans are known to navigate using magnetic fields (Kirschvink, 1986). Certain local geology, for instance rocks containing high levels of magnetic materials, such as iron, will distort the magnetic field in that area. It seems that cetaceans will try to avoid areas of particularly high geomagnetic anomalies and travel instead through areas with a lower, constant magnetic field. In certain areas this could cause them to be channelled towards a coastline or island; leading to stranding (Klinowska, 1985) (Walker 1992).

Data provision: The ESA's *Swarm* satellite trio have created the most detailed map to date of the geomagnetic anomalies present within the lithosphere. Data from this could easily be input into the algorithm.

2.1.3 Solar Activity

Studies have shown a correlation between periods of increased solar activity and increased numbers of stranding. More strandings occur during solar cycles less than the average of 11 years (Vanselow, 2005). Shorter solar cycles mean greater solar activity which can cause disruptions in the Earth's magnetic field. Disruptions from events such as solar flares could compromise cetaceans' ability to navigate using the magnetic field, leading to increased numbers of strandings (Vanselow, 2009). Currently a heliophysicist at NASA is carrying out a study to further explore this theory.

Data Provision: The ESA SSA Space Weather Service can provide real-time data and also forecasts regarding solar activity.

2.1.4 Movement of food sources

Sources of food, such as krill and squid are of primary

1 ESA, (2017), *International Satellite Derived Shallow Water Bathymetry Service*, <https://artes-apps.esa.int/projects/international-satellite-derived-shallow-water-bathymetry-service> (accessed: 14 June 2017).

importance to all species of cetaceans and they will often follow sources of food (Hastie, 2004). If this causes the cetaceans to enter areas that may be unsafe for them, it could lead to stranding. The movement of food sources is dependent on ocean temperature and current (Corey et al, 2006)(Pierce, 2007), which can both be monitored, allowing for an approximation of the location of food sources at any given time. Changing climate can also lead to changes to the locations of areas of cool, nutrient-rich water, leading to changes in the location of food sources (Evans et al, 2005).

Data provision: As it is not really feasible to track the food sources themselves, estimations of the areas certain species such as krill and squid may be in can be made using oceanographic data. This includes: currents, ocean temperature and tides. All of this data can be provided by the ESA Sentinel-3 and Sentinel 6 satellites.

2.1.5 Location / Known Migratory Paths

The location of cetaceans at any specific time could give the biggest indication to whether or not a stranding is likely to occur. Species which have a migratory path that takes them into high risk areas, or individuals that have become lost (deviated from their normal path/area) would be at an increased risk of stranding (Mazzariol, 2011). Sightings of cetaceans near to shores could give an early indication of an increased stranding risk.

Data provision: Most of the data for this factor would be received via sightings. There are many individual organisations around the world which record sightings of cetaceans in their area, making a record of location, species and characteristics, such as sex/ markings. Some countries have a central body which organises this data (e.g. the Sea Watch Foundation, UK), whilst most do not. A large number of these sightings will be from tourist excursions such as whale-watching trips. If a worldwide central body could be established, then a central database could be created in which all sightings, around the world would be recorded – providing much needed data for the algorithm and creating a central system allowing for greater studies of cetaceans in general. I have been in contact with a few different organisations (e.g. The Irish Whale and Dolphin Group, the central body for Ireland, and Marine Discovery Penzance, a well-established whale-watching trip from Cornwall, UK) who said they would happily share their data.

Data on migratory patterns is well known for some species, such as humpback whales, whilst not for others. When generalised migration paths are known, they can be included within the algorithm. Many studies are taking place using tracking to establish migratory paths, such as the study regarding Grey Whales in conjunction with the NOAA's Southwest Fisheries Science Centre[2].

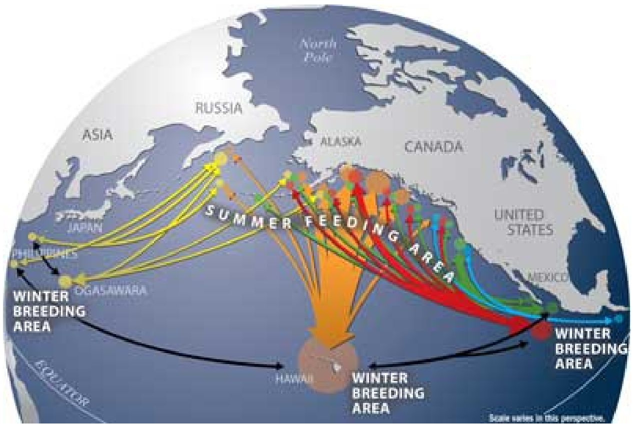

Figure 2: *Migratory Paths of North Pacific Humpback Whales. - Source: Hawaiian Islands Humpback Whale National Marine Sanctuary*

In time this may enable us to include increasing species' migratory paths within the algorithm.

2.1.6 Natural Disasters

As would be expected, in the event of natural disasters within the ocean, cetaceans are often adversely affected. Tsunamis can cause cetaceans to be washed a long way inland, even from far out at sea (Goff & Chagué-Goff, 2009). Studies also seem to show that cetaceans are sensitive to seismic waves (D'Spain et al, 2006)(Gordon et al, 2003), as such, it is possible the cetaceans could be affected by natural seismic events such as earthquakes (Kirschvink, 2000), leading to an increased likelihood of stranding.

Data provision: The Incorporated Research Institutions for Seismology (IRIS) collect data regarding earthquakes from monitoring stations around the world, creating one large real-time database. This data could provide the information needed regarding natural disasters for the algorithm.

2.1.7 Tides

Quickly receding tides could also be a factor in stranding, cetaceans in shallow water near to the shore could end up being left 'high and dry' if they don't remove themselves with the receding tide (Goodall, 1978). This would be particularly problematic when coupled with areas such as mud-flats or gently sloping beaches which cetaceans find harder to navigate (Brabyn & McLean, 1992). If they are unable to find the way out into the open ocean before the tide goes out, they will strand.

Exceptionally high tides that occur during a full moon, also known as 'King tides' or 'Spring tides', could further exacerbate this problem (McManus et al, 1984).

Data provision: Tides can be monitored using the ESA's Sentinel-3 and Sentinel-6 satellites.

2 NOAA, (2014), *Tracking Gray Whales,* <https://swfsc.noaa.gov/MMTD-GrayWhale-tracking/> (accessed: 14 June 2017).

2.1.8 Weather Conditions

Strong winds and events like storms or hurricanes could cause cetaceans to be pushed towards the shore. In addition, cetaceans are often seen to follow frontal convergences. If this ended up leading them towards land, they could be at increased risk of stranding (Walker et al, 2005).

Data provision: The ESA's Sentinel-1 satellite and the Meteosat satellites will be able to monitor marine weather conditions.

2.1.9 Social Interactions

The social nature of cetaceans is though to greatly contribute to mass stranding events. Especially in toothed whales *(odontoceti)*; observed to experience strong social bonds and the most commonly stranded *en masse* (Sergeant, 1982). In most cases mass strandings are made up of predominantly healthy individuals. It's thought that usually one member of the group has become ill and stranded itself on purpose in order to rest. However, due to the social nature of the cetaceans, the rest of the group strands themselves with it and won't leave (they will re-strand themselves even if re-floated) until the ill individual has either perished or recovered. (Simmonds, 1997).

Data provision: It is not possible to provide data regarding social factors as it cannot be quantitatively measured in any way. However, areas frequented by a larger number of highly social species could be given a higher risk of mass strandings occurring. This information would be gathered from sightings and scientific studies.

2.1.10 Harmful Algal Blooms

Harmful algal blooms (HABs), also known as 'red tides' naturally occur in various areas around the world. Direct ingestion or ingestion via bioaccumulation of the toxins in food sources can lead to severe illness in cetaceans, often ending in organ failure (Fire et al, 2010). They are also a common cause of mass strandings as any cetaceans passing through the area experiencing the HAB will likely become severely ill, seeking refuge on shores to avoid drowning (Torres de la Riva, et al, 2009).

Data provision: ESA's Sentinel-2 satellite is able to monitor water quality, including algal blooms. Not all algal blooms are harmful, but the ability to monitor and track the blooms accurately via satellite could provide data allowing the algorithm to predict if a mass stranding is likely to occur due to an algae bloom.

2.2 Human Factors

For strandings where human factors are responsible, the cetaceans are likely to be ill or injured. These individuals tend to strand themselves on purpose as swimming becomes too much of an effort and they need somewhere to rest and recover (Simmonds, 1997). In these cases medical attention is required before any re-floating attempts are made.

2.2.1 Pollution

Cetaceans can easily ingest or become entangled in discarded human waste such as plastic bags and old fishing nets, causing them to become unwell or injured (Secchi & Zarzur, 1999). Large-scale pollution events, such as oil spills, can also seriously harm cetacean health (Matkin, et al, 2008), leading to increased numbers of strandings.

Data provision: Oil spills can be tracked and monitored by the ESA's Sentinel-1 Satellite. Also, Researchers in France are working on a drift model that should be able to back-track from the point of stranding (for dead-stranded cetaceans) to provide an approximate point of death. In cases where mortality events were caused by ingestion of pollutants, such as plastics, the area in which this likely occurred can be identified (Peltier & Ridoux, 2015). Using data from this study it could be possible to isolate areas of high pollution to be included in the algorithm as a stranding risk.

2.2.2 By-catch and Boat Strikes

By-catch refers to the accidental trapping or entanglement of cetaceans within fishing nets. It's an exceedingly common problem which can lead to extensive injuries from abrasions and cuts to amputations of body parts, such as tail flukes (Kirkwood, et al, 1997). Boat strikes cause similar injuries, mainly inflicted by propellers.

Figure 3: *A sperm whale off the coast of Greece with scars almost 30cm deep, caused by colliding with a boat's propellor. - Source: PBS, Voyage of the Odyssey - Chris Johnson*

A large number of these injuries will be lethal. (Van Waerebeek, et al, 2007). When injured to this degree some cetaceans may strand themselves in order to recover, or may strand because they do not have the strength to prevent themselves from doing so.

Data provision: Peltier & Ridoux's research should also be able to identify areas with high incidences of by-catch and boat-strikes. With further development, this should allow for the algorithm to factor in these risks as a part of the overall stranding probability.

2.2.3 Acoustic Pollution

Anthropogenic noise is thought to be having devastating impacts of cetacean well-being. A significant number of mass stranding events can be correlated with the use of mid-frequency sonar in the nearby vicinity. This is often caused by military vessels carrying out training exercises (Filadelfo, et al, 2009). Studies show that the use of sonar seems to mainly affect cetaceans of the family *Ziphiidae*, causing trauma to the auditory system and a condition akin to decompression sickness; causing lesions and haemorrhaging of multiple organs (Rommel, 2006). Damage to the cetaceans' auditory system compromises their ability to navigate using echolocation, leading to an increased risk of stranding. Cetaceans may also swim towards shore to get away from the source of the affecting noise.

Data provision: As the majority of acoustic pollution is carried out by armed forces, the data it not readily available or easily provided. However, perhaps a number of armed forces around the world could be persuaded to share details of non-essential and unclassified excursions that include the use of potentially harmful sonar to be factored into the algorithm. However, this is just speculation.

3. *Creating the Algorithm*

PLEASE NOTE: ALL THE DATA IN THIS SECTION HAS BEEN RANDOMLY GENERATED TO AID IN THE EXPLAINATION OF THE ALGORITHM AND DOESN'T REPRESENT ACCURATE DATA VALUES.

The creation of an algorithm that can forecast strandings will require many steps and constant refining before any degree of accuracy is achieved. Analysis of a large global data set is required; without this the creation of the algorithm is not feasible.

3.1 Analysing Data Set to Calculate Individual Factor Probabilities

The provision of data is key. I have spoken to a few cetacean stranding organisations and charities who would be more than happy to provide data from past strandings that they have assisted in/ investigated, including the IWDG (Irish Whale and Dolphin Group). The BDMLR (British Divers Marine Life Rescue) and CSIP (UK Cetacean Strandings Investigation Programme) also make all of their stranding data and investigations publicly available. I'm certain that organisations worldwide will be more than happy to help, if the prior are any kind of example.

Once a large data set has been gathered it must be intensely analysed. Two different kinds of analysis will be needed. The first deals with 'static factors', those that stay relatively constant over long periods of time (for instance, coastline topography). The second deals with 'dynamic factors', those that are constantly changing.

3.1.1 Analysis of Static Factors

The globe will be split into squares, each of which will will have its own associated risk value. For the purposes of this example we will say that each square contains 10km^2 of the surface of planet Earth, though this will depend entirely on the degree of accuracy of the data provided. Then all of the static factors must be analysed.

For instance, the data will be analysed regarding coastline topography. It's though that gently sloping shorelines cause strandings, but what angle? The large data set will be compared to topography data of the ocean floor (found using bathymetry data).

How many of the strandings occurred on a coast that is not sloping or is steeply sloping? - if the number is significantly less than half then it is clear that gentle slopes have a greater stranding risk.

Then the analysis will consist of calculating a specific value for how much the stranding risk increases as the slope decreases. This will again be done through the use of the data set. How many strand on slopes of <20degrees compared to <19 degrees? And so forth. Through this analysis, approximate stranding risks due to the topography in that area, can be assigned to each square.

(km)	10 (km)	20 (km)	30 (km)	40 (km)	50 (km)
10	0.052	0.018	0.006	0.003	0.007
20	0.059	0.452	0.213	0.013	0.004
30	0.332	0.542	0.201	0.189	0.104
40	0.099	0.073	0.115	0.079	0.226
50	0.067	0.010	0.014	0.182	0.135

Figure 4: *Example of topography risk probabilities for a specific area*

This same process will be carried out for all factors classified as 'static factors'.

3.1.2 Analysis of Dynamic Factors

The analysis of dynamic factors is very similar to that of static factors, though its implementation within the algorithm is generally quite different. As dynamic factors are constantly changing, fixed risk values cannot be assigned to each square. Instead, the probabilities will change as new data is received – this is what allows for a real-time forecast. Through a similar analysis of the data set as done for static factors, the general increased risk caused by a dynamic factor can be found. For example, with acoustic pollution, a dynamic factor, it could be found that when mid-frequency sonar is used in the same 'square' as cetaceans, the stranding risk is increased by

0.451 on areas of coasts that are the first to be directly reached when following the current in that area. However, the increased probability of a stranding occurring on a stretch of coastline 100km away from where the main current leads to from the 'sonar square' is only 0.065. After analysis these relationships would need to be included within the algorithm.

For dynamic factors, there will often be interaction between factors. Distinguishing the exact nature of these interactions would allow the algorithm to operate along the lines of 'Increased probability of 0.123 in square xyz if factor 4 occurs in line with factor 8 within 50km'. This can only be achieved through a vigorous and extensive analysis of the data set.

3.1.3 Identifying Threshold Risk Values

Due to the nature of stranding events and the limitations of the algorithm, all coastline squares will have a constant risk value associated with them. It is necessary to know at what value the risk becomes severe enough to contact local authorities and warn them. This will be accomplished by again using the data set. Data collected at times of known strandings, will be run through the algorithm. This will be carried out with as much of the data set as is feasible; to maximise accuracy. The values in the squares in which the strandings actually occurred will be recorded and an average will be made, any anomalies will be discarded. This average value would be the 'threshold risk value'. If the algorithm was to predict this value for an area, authorities should be contacted. It may be possible that different threshold values are needed for different types of strandings and different areas.

3.2 The Algorithm

I feel it helps to visually represent the process of the algorithm, which is why a number of graphs and diagrams have been included.

Firstly, the algorithm will calculate the risk values associated with each factor for each square area. As shown in Figure 4. All of the values can then be superposed, with values for every factor being taken into consideration.

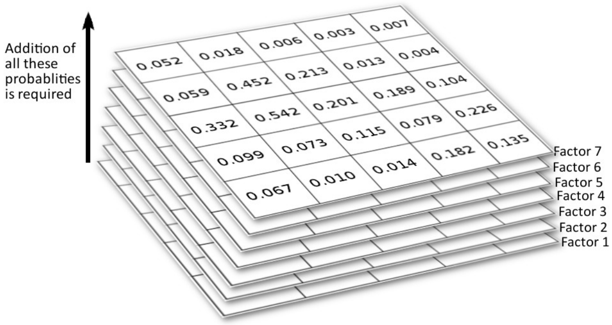

Figure 5: *Combination of risk probabilities associated with different factors*

These values can then be combined so there is a single risk value associated with each square.

(km)	10	20	30	40	50
10	0.136	0.067	0.033	0.012	0.046
20	0.156	0.876	0.445	0.022	0.026
30	0.556	0.787	0.323	0.350	0.243
40	0.284	0.121	0.321	0.389	0.398
50	0.178	0.023	0.037	0.356	0.322

Figure 6: *Example of overall probability values for a specific area*

These risk values can represented visually as a contour map where the Z-axis represents the probability of a stranding occurring, rather than height.

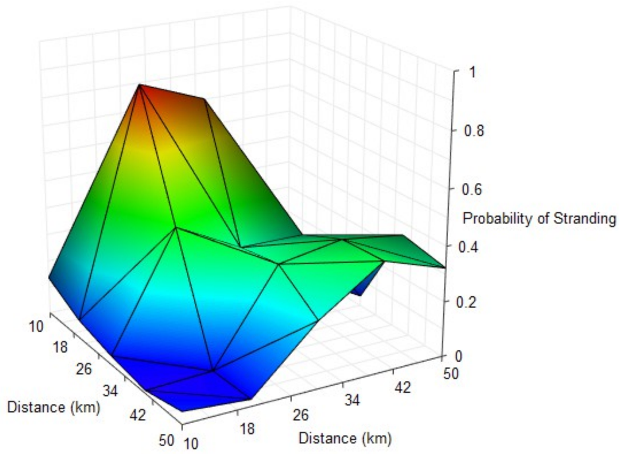

Figure 7: *Example stranding probability contour map for a specific area. - Created using TeraPlot*

Peak values show where strandings are most likely to occur at any given time. If these peaks exceed the threshold value then a stranding can be considered to be imminent and local authorities for that area should be contacted.

As new data is constantly provided and analysed, the probability values will change, giving new peak 'high risk' areas.

4. ***Response from Maritime Organisations***

I was able to get in contact with a few different cetacean rescue organisations from within Europe (the BDMLR, the IWDG and CRAM). The general response is a keen interest in the idea of the algorithm. It was also agreed upon that a large degree of international co-operation would be required to pull it off effectively. The idea of a global strandings database was also mentioned.

When it comes to particulars regarding the hypothetical implementation of the algorithm, my initial thoughts seemed to be generally agreed on by the representatives of the organisations I spoke to. This was that warnings would be sent to local authorities if there was a high stranding risk for their area – this would allow them to keep watches along coastlines and have the appropriate equipment and medical supplies ready, and teams on standby. There is also the potential to refuse the cetaceans access to shore. It also became apparent that pre-warning could even be useful in the case of dead strandings as almost all data we know about cetaceans comes from autopsies carried out after stranding events. With pre-warning, dead stranded cetaceans could be reached much sooner, limiting the state of decomposition or damage to the body by scavengers; allowing for greater scientific research.

However, I received only limited responses regarding how the organisations would want to receive warnings, and whether they would want a global governing body to organise everything. I think this lack of response on this topic was due to the limited time period in which I was able to be in contact with them. These decisions were slightly more weighty and perhaps were not feasible to come to a conclusion upon during the time available. They likely didn't wish to comment on things they could not be certain of, or commit to.

5. *International Co-operation and Governance*

There is already co-operation between different countries when it comes to the protection of marine mammals, like cetaceans. This is particularly prominent within Europe which has initiatives such as ASCOBANS (Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas), HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission), ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area) and the EU's Marine Strategy Framework Directive, all of which help to protect cetaceans within European waters. Africa has the Abidjan Convention (Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of West and Central African Regions) and the Nairobi Convention (Convention for the protection, management and development of the Marine and Coastal Environment of the Eastern African Region). South America is governed by CPPS (Convention for the Protection of the Marine Environment and Coastal Area of the South East Pacific). CMS (Convention on the Conservation of Migratory Species of Wild Animals), has parties from all over the world with many different continents being represented, but not all – it is missing some large coastlines, such as the USA, Canada and Russia. As a result, there is no global body that organises and co-ordinates the efforts of all of these different countries. It seems that for the algorithm to be effective, a central body would be needed, focused solely on the sustainability of our oceans for cetaceans.

6. *Conclusion*

This paper looks at the possible creation of an algorithm that would provide a forecast for cetacean strandings, giving an approximation of the time and location. This would allow for either the prevention or quicker resolution of the stranding by allowing communities and organisations to respond within a significantly reduced time-frame. The algorithm would use live data feeds from sources such as the ESA Sentinel satellites, and run this through a pre-determined set of requirements and conditions that would allow it to calculate the probability of strandings occurring for all areas. This complex nature of the algorithm is due to the interaction between all of the different factors. The risks associated with each of these factors will be calculated in conjunction with an extremely large data set of past strandings, provided by organisations around the world.

If the creation and implementation of this idea was successful, many cetacean lives could be saved. This not only benefits the individuals who would be rescued but also has a direct effect on the sustainability of our planet. A large number of cetacean species are endangered or threatened due to past human actions (such as the extensive whaling of the 1800-1900s), and continue to be threatened today by things like pollution, by-catch and boat strikes. The opportunity to save a greater number of cetacean lives by rescuing them from stranding may not make up for these indiscretions, but it's a start.

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