7-20-2012

A Generalized Leslie Matrix Model for Projections of Area V Humpback Whale Population Demographics

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Vildana Hajric, Class of 2011

Australian Humpback Whales have been harvested since the late 1700's, helping to spur the country's first primary industry. Such continual hunting of the species diminished its stock to near-extinction, forcing the International Whaling Commission to create a ban on commercial whaling of humpbacks in the 1960's. However, countries such as Japan and Norway that depend on whaling as an integral part of their meat industries and cultural traditions have commenced whaling under the guise of scientific research. This paper aims to calculate humpback whale population growth rates of the eastern Australian area V stock using survivorship and fecundity rates of different classes within the group. Furthermore, it aims to show that scientific whaling has a negative effect on population growth rates, helping to diminish the stock's population numbers. Lastly, the paper gives recommendations for future recovery plans that could potentially ensure that the area V humpback population increases with time.

Introduction

In the early 1600's, European explorers and traders came in contact with the previously unexplored Australian continent looking for new land to claim under the name of their home countries. The area was officially claimed by Captain James Cook in 1770, a British explorer who created early settlements in the Sydney area (McKernan, n.d.). By 1788, however, not many areas had been developed for settlement and colonizers were faced with hunger due to lack of jobs and food ("Australia's," 1995). Looking to build industries and jobs, they started hunting whales, using their meat and products as trade items. Since then, whales have been hunted for a number of different reasons around the coasts of Australia. The humpback whale, a baleen whale often found off the coasts of New South Wales, was targeted and hunted into near extinction in the Pacific Ocean along eastern Australia. Its numbers decreased drastically between the 1780's and 1960's causing concern among the international community about its preservation.

History of Whaling

Whaling off the coasts of Australia commenced as a smaller industry used primarily for food resources in the late 1700's. By the 1830's, whaling officially grew into a commercial business when Australia became a valuable region for the export of raw materials, such as whale products, to Britain and the United States ("Australia's," 1995). Whaling initially used smaller boats, but methods were later aided with harpoons, guns, and other weapons. Whalers sought after all types of whales, including killer, minke, and humpback whales. The animals were being harvested for a number of different reasons. As Australia offered little food sources elsewhere,

hunters mainly focused on whales because they provided a reliable source of food ("Killers," 2009). The settlers were in luck because whales were found in large stocks off the coast of Australia. Within a couple of years, a number of different whaling businesses sprung up along the coast near modern Sydney, and traders around the world, especially Britain and America, started visiting Australia to profit from this industry. The European colonizers, thus, turned whaling into Australia's first and oldest primary industry ("Australia's," 1995).

Yet whaling industries did not only spring up in Australia—countries all around the world also harvested whales for their products. The profession drew thousands of men to work in the whaling business as whale products were coveted and brought many financial rewards (McNamara, 2009). However, as the industry grew over the years, the number of whales declined and many countries became concerned with the rapid depletion of whale populations. The League of Nations became particularly alarmed and drafted the Geneva Convention on the Regulation of Whaling treaty in 1931. The treaty was signed by twenty-two countries, including Australia, and was revised a number of times, eventually leading to the establishment of the current International Convention for the

Regulation of Whaling (ICRW) in 1946. The ICRW then established the International Whaling Commission (IWC) whose aim was to protect and conserve rapidly-depleting whale populations. The IWC worked towards protecting certain species of whales, specifying sanctuaries for stocks, and setting limits on how many whales could be harvested per year. Through its practices, the IWC has been able to help recover whale species from near extinction and plans on working towards eliminating other threats to whale populations in the future ("IWC: History," 2008).

Whaling as Part of Scientific Research

Even though the IWC aims at protecting and conserving whales, it does allow its member countries to apply for permits to hunt whales for scientific purposes. These provisions are given out because countries, such as Japan, that once heavily relied on whale products for uses in many of their industries found scientific whaling as a loophole to illegally engage in whaling as they had done before restrictions were imposed. Therefore, countries with permits are allowed to "kill, take and treat whales for scientific purposes and requires that the animals be processed so far as practicable once the scientific data has been collected" ("IWC: Scientific," 2008).

Figure 1: Japanese boat whaling for scientific research (Modified from: "Samir's Weblog," 2008).

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However, since the IWC started giving out permits for this purpose, more than 11,000 whales have been taken by only four countries: Japan, Iceland, Norway, and Korea. This poses a problem for whale conservation because a large number of whales are killed in the name of science, yet scientific whaling has failed to conduct valuable research about whales that could not have been done through non-lethal research. These practices have been subject to heavy diplomatic and international criticism, yet progress to end scientific whaling has been nothing but slow (Rothwell, 2007).

The country of Japan has been particularly spotlighted as it has tried to overturn the IWC's efforts to stop whaling worldwide. Under its research programs known as Japan's Research in the Antarctic (JARPA) and JARPA II, Japan has continued whaling humpbacks that travel along the coasts of Australia. Japan claims that not enough scientific research has been done to fully understand how to successfully manage whale stocks ("ICRW: Background," n.d.). A majority of the whales Japanese researchers harvest are ones that take seasonal migrations along Australia's eastern coast, known as area V humpbacks. All humpback whales traveling in the Southern Hemisphere are divided into six different stocks based on migration patterns and aggregations in the Antarctic during their feeding season, and the whale stock most commonly observed along the eastern coast of Australia is the area V humpback. It is contained within 130ºE - 170ºW and is the same stock that is "observed migrating along the east coast of Australia, past Norfolk Island, both

coasts of New Zealand and throughout the South Pacific Islands" (Anderson *et al.*, 2004). One of the most shocking discoveries, however, is that Japan sells whale meat on its markets, all of which comes from whaling done under the guise of such scientific research and purpose, as has been Japanese tradition for hundreds of years (Head, 2005). Nevertheless, "Japan's increase in the number of whales it kills has become an abuse of a legal right to engage in scientific whaling" and many members of the IWC have proposed that an end needs to come to JARPA programs (Rothwell, 2007).

Question

With current trends of whaling, the area V humpback whale population is being affected. This paper aims to discuss whether or not the stock population is decreasing, what the effects of whaling under the name of scientific research are, and how the population would be affected if scientific research whaling did not exist.

Humpback Whales

Humpback Whaling

When Australia's whaling industry was in its prime, humpbacks were targeted, specifically because hunters could use their oil for soaps, lubricants, perfumes, candles, etc. and their baleen for the creation of umbrellas and corsets (Egan, 1995). However, their harvest was unregulated until recently, bringing them to a point of near extinction. Nearly 95% of humpback whales were eliminated as Australia and New Zealand harvested more than

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40,000 humbacks migrating from the Antarctic along Australia's eastern coast in the 1800's and 1900's. The area V stock contained around 10,000 whales in its un-harvested state, but only 500 individuals survived by the year 1962 (Chittleborough, 1963, p. 34). Whaling of humpbacks officially ceased in 1963 in Australia, and ended worldwide in 1965 after the international community recognized a dramatic decline in population numbers. This decline incidentally led to the demise of Australia's whaling industry and commercial whaling in Australia ceased in 1978 with the closure of Australia's last whaling station in Western Australia ("Department," 2007). Currently, Australia has listed its humpback whale populations as vulnerable under the Environmental Protection and Biodiversity Conservation (EPBC) Act ("Australian Government," 2005, p. 5).

Life History

The humpback whale (*Megaptera novaeangliae*) is found all over the world including in the North Pacific, North Atlantic, and Southern Hemisphere (Perrin, 2008, p. 582). It is a baleen whale, meaning it

Figure 2: Mother and calf on southern migration (Modified from: "Conforth Images," 2009)

has special sieves in its mouth known as baleen plates. In Australia, they are one of the most commonly sighted whales on the eastern and western coasts of the country ("Whale Watching," n.d.). They are stocky, stout, and extremely large with outsized pectoral fins, which it uses for breaching and slapping water in acrobatic ways (Perrin, 2008, p. 584). It receives its name "humpback" because it arches its back out of water in preparation for a dive for air (Harrison, 2005). The top of its back is dark blue or black and its underside can wary anywhere from black to white to marbled patterns, characteristics scientists use in demographic studies of the whales. Each individual has his or her own particular pattern and shading, with variations being noticed among whales originating from different parts of the world (Paterson, 2000). More interestingly, however, is that humpbacks grow to about fifty-two feet long and can weigh thirty to fifty tons, making them a very slow moving animal ("Australian Antarctic," 2009).

All humpback whales take long and arduous seasonal migrations—the longest of any mammal. They mate in warmer waters during winter seasons and travel to colder

Figure 3: Distribution of humpback whales around Australia (Modified from: "Department of Environment," 2009)

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waters during the spring, summer and fall seasons to feed (Perrin, 2008, p. 583). Area V humpback whales breed and calve on the northern side of the east coast in warmer areas such as the Great Barrier Reef and the Northwest Shelf during the winter ("Australian Antarctic," 2009). They then embark on their migrations, traveling in large, loose packs with their calves from northern Australia towards colder, polar waters during the summers in search of food (Perrin, 2008, p. 583). Adult whales do not feed during the winter, managing to survive off their layers of fat during that time, and feed enough during summer, fall, and spring seasons to produce milk for their future, young calves ("Animal Info," 2005). Once in the polar waters, they eat twice a day and tend to feed on planktonic crustaceans, including krill, small fish, and plankton (Perrin, 2008, p. 583).

Figure 4: Area V Humpback whale migration calendar (Modified from: Paterson, 2000).
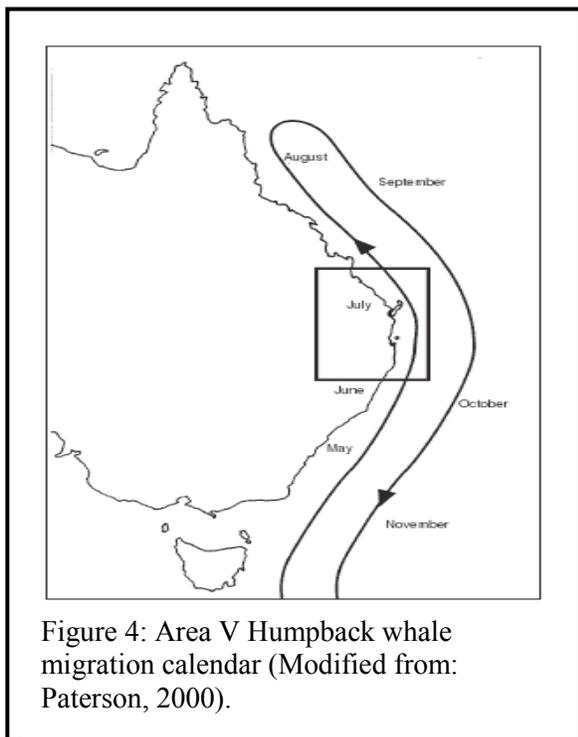
Female humpbacks give birth every one to three years. Twins are very rare and over 99% of the time only one calf is born to a female. The gestation period of humpbacks is around eleven to twelve months. Calves are born about fourteen feet long and weigh around two tons. Babies are nurtured with their mothers' milk and are weaned sometime between a year and 18 months and reach puberty between ages three and six (Paterson, 2000). Once they are born, the mother and calf pair travels to the colder polar waters together in conjunction with other, looser groups of whales. The only strong bonds among groups are found between mother and baby pairs. Because of their large size, they are only able to travel three to nine miles an hour and have even slower speeds during the babies' feeding times ("Australian Antarctic," 2009). Due to their slow speeds and extremely large, noticeable bodies, humpback whales were prime targets for early whaling industries ("Australian Antarctic," 2009).

Demographic Model

A demographic model is used to calculate and describe population change over time as it is affected by certain factors. For this study, a Leslie Matrix model is implemented to determine population growth rates for Area V humpback whales using survivorship abilities and fecundity rates for specific age classes.

Leslie Matrix Model and Methods

A Leslie Matrix model is a basic tool used for population studies where specie extinction or survival rates are

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calculated using parameters of age or class-specific survivorship abilities and age or class-specific fecundity rates (Liebler, 2003, p. 163). It can be used to determine population growth rates as well as age distribution within populations over time. Individuals of studied populations are grouped by maturity and each group records the number of individuals for every age bracket (Liebler, 2003, p. 163). For this study, Area V humpback whales have been condensed into four groups, according to their maturity levels: infants, sub-adults, adults, and post-adults. Infants (class 1) were defined as age groups 0-2 because once whales are born the yearlings stay with their mothers for 12 to 18 months (Chittleborough, 1957, p. 2). Sub-adults (class 2) were defined as age groups 3-6 because these are weaned but not yet sexually mature whales (Chittleborough, 1963, p. 54). Adults (class 3) were defined as age groups 7-20, as this is the age period when humpback whales are sexually mature. The post-mature group (class 4) was defined as age groups 21-45 and whales in this class do not reproduce (Chittleborough, 1963, p. 55).

Each class or group is characterized by fecundity (F) or the average number of female offspring produced by a female. Class 1 is denoted by F_1, class 2 by F_2, class 3 by F_3, and class 4 by F_4. Groups are also characterized by probability of survivorship through each age class (P) which is the survival rate of each age group from infant to sub-adult to adult to post-adult. Class 1 is denoted by P_1, class 2 by P_2, class 3 by P_3, and class 4 by P_4. From these assumptions it is possible to construct a deterministic model of population growth rates by calculating how fecundity rates and survivorship abilities affect the number of individuals in each class, thus projecting growth or decline within the overall population.

Basic Assumptions

Because only mature adults are capable of reproduction, only class 3 (F_3) can be used to calculate fecundity rates for the different classes. That means that $F_1 = 0$, $F_2 = 0$, and $F_4 = 0$. In order to calculate F_3, however, the average number of calves female humpback whales have during their adult lifetime is used, which is 6-9 calves—6 being the lowest end of reproduction and 9 being the highest. This was calculated based on the fact that humpbacks are sexually mature between ages 7-20 and have, on average, one calf every two years with a one-year resting period every two cycles (Chittleborough, 1963, p. 55). Furthermore, 37% (0.37) of females give birth on a two-year cycle (one calf in two years) (Chittleborough, 1963, p. 58, 1957, p. 1). If it is assumed that the most conservative number for reproduction is 6, then the average number of female offspring produced by a female whale during this timeframe for class 3 (F_3) is (6 * 0.5 * 0.37) = 1.11. If it is assumed that the high end for reproduction is 9 calves, then F_3 = (9 * 0.5 * 0.37) = 1.67. Therefore, F_3 equals 1.11 when the average number of calves used is 6 to calculate fecundity rates, and equals 1.67 when the average number used is 9 calves.

To estimate survivorship probabilities, approximations from a previous study were used which

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calculated that $P_2 = 0.7103$, and $P_3 = 0.9100$ (Jackson, 2009). Because the study did not have approximations for P_1, the survivorship rate of infants, information was used from the Chittleborough 1965 paper to determine P_1. The study states that the average number of births per 100 females was 18.6 in three years of sampling. The average number of calves surviving to age 3 (sub-adult) was 11.9, 13.4, and 15.1. By averaging those numbers together and dividing them by 18.6, it was calculated that $P_1 = 0.7240$. Therefore $P_1 = 0.73$, $P_2 = 0.71$, and $P_3 = 0.91$ (Chittleborough, 1963, p. 115).

Lastly, in order to calculate population growth rates, fecundity and survivorship rates need to be evaluated in conjunction with the population sizes of the four different classes. To estimate current population sizes in area V humpback whales, the Chaloupka *et al.* 1999 study was used that states that the stock has 156 sub-adults and 813 adults (Chaloupka, 1999). The study also states that these numbers represent between 30-50% of the entire population. To calculate the number of calves for the same time period, it was assumed that approximately 72.4% of calves survive to sub-adults. Therefore, the estimated number of calves is 215. If it is assumed that these class size numbers represent 30% of the entire population, then there are 717 calves, 520 sub-adults, and 2710 adults at the first time point of the modeling (Chaloupka, 1999). Finally, the number of post-adults is presumed to start at 0 at the first time point in the modeling because it does not influence the population growth rate.

Basic Results

Using the calculated numbers for survivorship (6 calves per year, $F_3 = 1.11$), fecundity ($P_1 = 0.73$, $P_2 = 0.71$ and $P_3 = 0.91$), and class sizes (infants=717, sub-adults = 520, adults = 2710) it is simple to determine the population growth rates given these parameters and the Leslie Matrix model using the program Populus. The results show that the population growth, characterized by λ, is 0.83, or $\lambda = 0.83$. Because the resulting number is less than one, the population is shrinking under these circumstances. When projecting population change for the next couple of decades using this result, it is clear that humpback whales would become extinct by 2050 under these assumptions. However, if the population growth rates using 9 calves per year, or $F_3 = 1.67$, were to be calculated, then $\lambda = 0.95$. The resulting number is still less than one. Therefore, when using these calculations to project population change in the next couple of decades, the area V humpback whale population would still be shrinking under such assumptions and whales are likely to be extinct by 2150.

$$\begin{bmatrix} 0 & 0 & 1.11 & 0 \\ 0.73 & 0 & 0 & 0 \\ 0 & 0.71 & 0 & 0 \\ 0 & 0 & 0.91 & \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 1.67 & 0 \\ 0.73 & 0 & 0 & 0 \\ 0 & 0.71 & 0 & 0 \\ 0 & 0 & 0.91 & \end{bmatrix}$$

Leslie Matrix Equations depicting

Calculations using $F_3 = 1.11$ and $F_3 = 1.67$

An explanation as to why humpback whale numbers are decreasing can be found by calculating whether or not scientific whaling impacts stock numbers, as area V humpback whales are still being harvested under the guise of scientific research. In order to calculate true population growth rates, current levels of scientific whaling must be included to investigate the effect of greater or lesser whaling which can be done by manipulating the survivorship probability values of the stock.
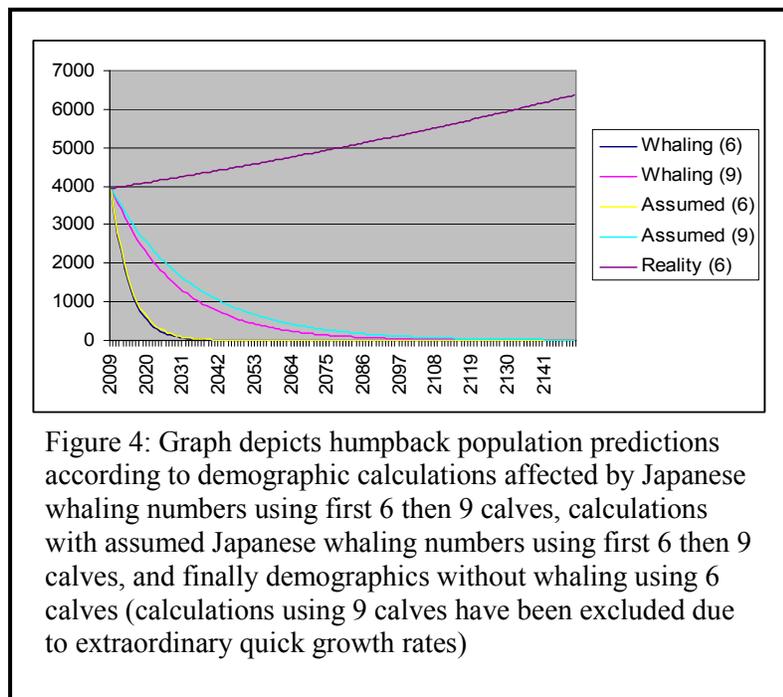
Effects of Whaling on Calculated Results

Whaling of area V humpback whales happens in the Antarctic once they migrate to the region during their mating seasons. It is mainly done by Japanese hunters who claim to harvest whales in order to conduct scientific experiments that could later be used to create better protection programs for whales. However, their whaling greatly impacts the population of the humpbacks as they have been known to take more whales than the IWC allots

them for a specific year. Japanese researchers claim to be taking fifty whales per year from the region or around 0.1% of the total population of humpback whales ("Embassy of Japan," 2009). They claim that these numbers have no effect on the population numbers. However, fifty whales amount to 1% of the estimated area V population, ten times the number the Japanese claim to harvest. These practices need to be calculated into population growth rates in order to get a more accurate estimate of population change over the years.

As stated before, the P values indicate the probability rate that a female survives to the next class. It is known that $P_1 = 0.73$ and that whales spend two years in that class before moving to the next one. Therefore, their yearly survivorship equals $(0.73)^{1/2}$ or 0.85. $P_2 = 0.71$ and whales spend four years in that class before moving to the next one. That means that their yearly survivorship equals $(0.71)^{1/4} = 0.92$. So, if it is assumed that whaling takes 1% of the population each year (50 whales / approx 5000 total), then putting those numbers back into the survivorship calculations makes $P_1 = 0.86 * 0.86$ instead of $0.85*0.85$, and $P_2 = 0.93^4$ instead of 0.92^4. The new survivorship rates therefore are $P_1 = 0.74$, $P_2 = 0.72$ and $P_3 = 1.0$. Using these numbers it is easy to calculate the effect no whaling would have on the humpback population as was done previously. The calculations show that with 6 calves per year $\lambda = 0.84$, and with 9 calves per year $\lambda = 0.96$. Because both these numbers are less than 1, the population would be projected to be shrinking in either case.

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However, it is a possibility that the whaling numbers provided by the Japanese are not accurate. Therefore, a more representative number of whales

Figure 4: Graph depicts humpback population predictions according to demographic calculations affected by Japanese whaling numbers using first 6 then 9 calves, calculations with assumed Japanese whaling numbers using first 6 then 9 calves, and finally demographics without whaling using 6 calves (calculations using 9 calves have been excluded due to extraordinary quick growth rates)

harvested or killed each year using more realistic factors can be calculated. It is know that the Japanese take a total of 930 whales in the Antarctic including minke and blue whales ("Act Now," 2008). Out of that number, it is estimated that blue whales are taken least. It can, therefore, conservatively be estimated that 20% of the harvest is blue whales and that the rest of it is split between minke and humpback whales. This means that minke and humpback whales are harvested at 40% each. For humpback whales, that means that 40% of harvest * 930 whales = 372 humpbacks. Those 372 whales equal nearly 10% of the area V humpback population, not 0.1% as the Japanese claim. Under these assumptions, if whaling stopped, then P_1 = 0.95*0.95 =0.91, P_2 = 1.0 (becomes 1.0 with just a 7% average return), and P_3 =

1.0. Calculating population change with 6 calves per year produces λ = 1.0034. This number is very close to 1.0, which means that the population stays stable, not growing nor shrinking. When calculating it with 9 calves per year λ = 1.15. This number gives a 15% population increase per year, meaning that without the scientific whaling done by Japanese researchers, humpback populations are more likely to be stable or growing.

Conclusion and Recommendations

Under the current conditions, it has been calculated that area V humpback whales are facing extinction, perhaps as soon as 2050 or 2150. In reality, because of the way the model is calculated with age groups, extinction rates are probably closer to 2070 or 2170 and have a 20-year lag within age groups. If the current amount of whaling was stopped at levels cited by Japanese researchers, populations would continue to shrink. This is very strange because without external mortality through whaling one would think the population would be at carrying capacity, meaning that the population growth rate or λ would be close to 1.0. Under perhaps a more realistic assumption of whaling (10% instead of 1%), calculations show that if whaling were to stop, λ would indeed be 1.0034 (under an average of 6 calves per female), which would indicate a population near carrying capacity. Under the assumption of 9 calves per

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female and no whaling at the 10% level, λ = 1.15. However, an average of 6 calves per female is probably more accurate than 9 calves per female, and perhaps the 10% estimate is closer to reality than the 1% calculations, especially because other studies have found similar population growth rates to be true (Noad *et al.*, 2007).

It is clear that whaling of humpbacks poses an apparent and eminent danger to the animals but numerous countries that depend on whaling as part of their main industries have been pushing for reform within the IWC to allow commercial whaling to legally recommence ("Australian Government," 2005, 6). Humpback whales are also threatened by many other anthropogenic activities and factors, including climate change, pollution, whale watching, illegal whaling, fish nets, and collisions with boats ("NPCA," n.d.). In addition, it is very possible that the specie's habitats will be destroyed by climate change factors. In the future, "humpback whale migration, feeding, resting, and calving site selection may be influenced by factors such as ocean currents and water temperature" which are influenced by climate change ("Australian Government," 2005, p. 7). This could impact humpback whale populations in many negative ways, contributing to their shrinking numbers.

Through careful monitoring of populations and their habitats, the Australian government can help ensure that humpback whales do not become extinct in the near future. This can be done by implementing programs and scientific research methods that do not interfere with whale migratory paths, feeding and breading grounds in order to learn about the humpbacks and their lifestyles. To accomplish this, scientists must locate specific migratory routes of area V humpback whales in non-disturbing ways, which can be done through careful observation using technological advances and satellite imagery. Such routes could then be sanctioned by the government and put under satellite watch to ensure complete specie protection. Sanctions would help ensure that no invaders come near their migratory paths without permission or valid excuses validated by the government. Australia has already taken measures to ensure that humpback whales are protected in established sanctuaries and within parameters of the Exclusive Economic Zone (EEZ), an area over which a country has special rights, but needs to ensure that such areas are completely guarded at all times ("Australian Government," 2005, p. 5). Furthermore, the Australian government can impose policy limiting the activities of whale watching industries and the impacts they make on their tours. Whales should be left undisturbed and should be observed from a distance, allowing tourists to see them while not interfering with their lives. Finally, similar restrictions should be placed on fishing boats and other fleets traveling near migratory or sanctuary humpback areas. Measures should be taken to ensure that no whales get caught in fishing nets, none are hit accidentally by boats, and pollution to their waters is minimized by reducing waste that is discarded by all ships. Fines should be

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put in place for all who disturb the regulations.

Once such measures are taken, humpback whales would be protected to a certain degree. However, the Australian government needs to focus on eliminating the scientific whaling done by Japan and place a ban on their practices. Even though restrictions already exist on the amount of humpbacks that can be harvested per year by the Japanese, Australia and other countries need to work together towards lowering such rates and monitoring how many whales are truly harvested by Japanese ships until a total ban is established on whaling. This can be accomplished by putting pressure on the

Japanese to stop their whaling and urging the international community to do the same, as non-lethal whale research can provide all needed information about whales. The Australian Minister for the Environment, Peter Garrett has proclaimed that "non-lethal whale research can provide all the information needed to understand and conserve whales and so called 'scientific whaling' is unnecessary" (Garret *et al.*, 2009). Therefore, scientists need to make it clear that humpback whales are a threatened and endangered specie, that survival of even 50 humpbacks can make a difference on stock populations, and that scientific whaling needs to come to an end.

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