Migratory destinations and sex composition of sei whales (*Balaenoptera borealis*) transiting through the Azores

RUI PRIETO[1], MÓNICA A. SILVA[1,2], MARTINE BÉRUBÉ[3], PER J. PALSBØLL[3]

[1]Centro do Instituto do Mar (IMAR) da Universidade dos Açores, Departamento de Oceanografia e Pescas, Rua Prof. Doutor Frederico Machado, 9901-862 Horta, Portugal. [2]Biology Department, MS#33, Woods Hole Oceanographic Institution, Woods Hole MA02543, USA. [3]Faculty of Mathematics and Natural Sciences Marine Evolution and Conservation, Centre for Ecological and Evolutionary Studies, P.O. Box 11103 9700 CC, Groningen, The Netherlands.

ABSTRACT

Under the Revised Management Procedure (RMP), reliable and up-to-date information is needed to create plausible hypotheses about stock structure and migration. Information on migratory patterns for the North Atlantic sei whale (*Balaenoptera borealis*) is scarce and mostly based on deficient and obsolete data. Here we present results from satellite telemetry and molecular sexing of sei whales occurring off the Azores Islands. Eight whales were equipped with satellite tags between 2008-2009, seven during the spring migration and one in September. All northbound whales moved to the Labrador Sea, suggesting philopatry to the feeding ground. The whale tagged in September moved southeast, until the signal was lost between Madeira and Canary Islands. In combination, our telemetry results point to a complex migration process that can involve longitudinal movements between the two sides of the ocean basin, in addition to the expected latitudinal movements. The sex of 24 whales was determined using skin samples obtained from between 2005 and 2010, 14 of which (58.3%) were males. Due to the small sample size, departure from parity is questionable. Seasonal gender distribution suggests an excess of males in the early season, contrary to data from other regions suggesting that pregnant whales are in the vanguard of the migration. This may result from a sampling issue, but it could also reflect different behaviour by females during migration both to and from feeding grounds.

ATLANTIC OCEAN, MANAGEMENT PROCEDURE, SEX RATIO, BREEDING GROUNDS, FEEDING GROUNDS, MIGRATION, MOVEMENTS, SITE FIDELITY

INTRODUCTION

A proposal to initiate a *pre-Implementation Assessment* of sei whales (*Balaenoptera borealis*) in the central North Atlantic has been submitted by Vikíngsson *et al.* (2010) to the International Whaling Commission (IWC) Sub-Committee on the Revised Management Procedure, but due to agenda limitations it was not possible to discuss it (IWC 2011). However, during its 63th meeting in 2011, the Sub-Committee agreed on a workplan that included the review of the proposal for *pre-Implementation Assessment* of North Atlantic sei whales during its 2012 meeting (IWC 2011).

Under the Revised Management Procedure (RMP), reliable and up-to-date information is needed to create plausible hypotheses about stock structure and migration. Currently, stock boundaries are already defined by the IWC for several whale populations worldwide. Unfortunately, data used to establish stock identity in the past (catch distribution, length distributions, mark-recapture, and biological parameters) is not always appropriate to define biological stocks (Donovan 1991). That is the case for the North Atlantic sei whale, for which three stocks were adopted in 1977, despite the admission that the identification of stocks for this species in the North Atlantic was very difficult (Donovan 1991).

Evidence of stock identity for the North Atlantic sei whale was reviewed by Mitchel and Chapman (1977) for the Northwest Atlantic, who suggested that two stocks occurred off Canada, termed the "Labrador stock", and a "Nova Scotia stock". It was hinted that the Nova Scotia stock whales had their distributional range along the North-American shelf (Fig. 1 in Mitchel and Chapman 1977) and that West Greenland records probably belonged to the same stock as the Labrador sei whales. Mitchel and Chapman further suggested a possible link between sei whales from Labrador and the Denmark Strait, although they held that link as improbable. The only other suggestion for stock structuring of sei whales in the North Atlantic was presented by Horwood (1987) based on the revision of calculations of length at sexual maturity for males taken in Norway, Canada and Iceland. He noted that the values reported for males from Canada were lower than those for Norway and Iceland (12.0, 12.8 and 12.7 m, respectively), but he also remarked that better agreement would be achieved if a different combined testes weight at maturity had been used in the Canadian study, comparable with that used in the other two studies. It is relevant to mention that the Canadian samples originated from whales taken in Nova Scotia (Mitchel and Kozicki 1974) and, therefore, from the purported Nova Scotia stock, which is not clear in Horwood's account.

Migration behaviour of the species in the North Atlantic is also poorly understood and existing theories are highly speculative (discussed by Prieto *et al.* 2011). As mentioned above, Mitchel and Chapman (1977) suggest a migration of whales belonging to the Nova Scotia Stock along the North American coast, with a wintering area placed somewhere off Florida. For the eastern North Atlantic, the most

widely cited theory is based on the (unverified) migration pattern suggested by Ingebrigtsen (1929), by which sei whales would winter south of the Iberian Peninsula and off northwest Africa and, in spring, migrate north up the mid-Atlantic and off the western continental slope of Europe to the feeding grounds around Iceland, Scotland Norway and Arctic Ocean.

Additionally to the evident knowledge gaps, it's been shown by Prieto *et al.* (2011) that most information on north Atlantic sei whales is more than 25 years old and based chiefly on whaling records. In consequence, any stock structure that could have existed in the past may have, since, been altered by redistribution of whales resulting from population reduction, redistribution of prey and environmental changes.

It seems clear that to initiate a *pre-Implementation Assessment* for North Atlantic sei whales, better and more up to date information is needed to back hypotheses about stock structure and migrations of the species in this ocean.

The results presented in this paper arise from recent studies on sei whales migrating through the Azores and are intended to complement the information available to create scenarios about sei whale stock structure and migration in the North Atlantic.

METHODS

Migration inferred by satellite telemetry

Satellite-monitored platform transmitter terminals (PTT) housed in surgical grade stainless steel (model SPOT5-implantable, Wildlife Computers) were implanted in eight sei whales using a modified commercial version (model ARTS/RN, Restech Norway) of the air-powered satellite tag deployment system described by Heide-Jørgensen *et al.* (2001). Tags were equipped with barbed darts with a four-bladed tip to help in penetration and to act as an anchor after implantation. All tags were cleaned with 70% ethanol to remove contaminants from manufacture and handling and then sterilized under UV light after which they were stored in sterilized sealed bags. Prior to implantation the tip was covered with Gentamicyn cream to act both as antibiotic and lubricant. Whales were tagged off Faial and Pico islands in the Azores archipelago from May to June in 2008 and 2009, except for one whale that was tagged in late September 2009. In 2008 the tags ran under a duty cycle, being programmed to transmit every hour of the day, every other day, in an effort to extend battery life. In 2009 no duty cycle was applied to the tags. All procedures followed the guidelines of the American Society of Mammalogists (Gannon *et al.* 2007) and fieldwork was developed under permits issued by the administrative authorities of the Autonomous Region of the Azores (Portugal).

Argos-derived surface positions were estimated with the Kalman processing algorithm (Anon. 2011) and used to reconstruct the tracks of the tagged whales in a Geographic Information System (GIS; ArcGIS 9.3) and to calculate movement statistics.

Sex composition of whales migrating through the Azores

Biopsy samples of skin and blubber were collected from sei whales off Faial and Pico islands in the Azores between 2005 and 2010, using biopsy darting similar to that described by Mathews *et al.* (1988). The sex corresponding to each sample was determined by the amplification of the ZFY and ZFX specific sequences as described by Bérubé & Palsbøll (1996a, 1996b). All procedures followed the guidelines of the American Society of Mammalogists (Gannon *et al.* 2007) and fieldwork was developed under permits issued by the administrative authorities of the Autonomous Region of the Azores (Portugal).

RESULTS

Satellite tags were deployed on four sei whales in 2008 and on other four in 2009 (Table I; Figure 1). Tag lifetime (from implantation to last transmission received) varied from 16 to 116 days and valid locations were received for periods from 8 to 70 days. Reception of the first transmission from the tag was delayed from four to 46 days in five of the tagged whales, rendering incomplete tracks for those individuals (Figure 1). Of the eight tagged individuals, seven were tagged between May and June, during the spring migration to higher latitude feeding grounds and one (80712) was tagged in late September, presumably during the autumn migration to lower latitudes. All individuals tagged during the spring migration moved to the Labrador Sea region.

The three whales for which we obtained data during the migratory phase of the displacement between the Azores and the Labrador Sea (80695, 80711, 80717) maintained a median heading between 317° and 321° and a mean speed between 6.6 and 9.7 km/h until approaching the North Atlantic Current (NAC)

boundary associated with the Subarctic Front (Belkin and Levitus 1996). After arriving at the NAC boundary, mean speed dropped to between 4.3 and 5.9 km/h.

We received data for a period of 34 days from the whale tagged in September 2009. It moved southeast with a calculated mean speed of 5.3 km/h, and was between the Madeira and Canaries archipelagos when the signal was lost.

Sex was determined for 24 whales, 14 of which were males, corresponding to 58.3% of the sample. The sex seasonal distribution of sampled animals is shown in Figure 2.

DISCUSSION

Migration inferred by satellite telemetry

It is not possible to know where the whales that were tagged in the Azores originated from. However, it seems unlikely that whales originating from hypothesized wintering grounds located somewhere off the American coast would head to the Azores and then veer to the Labrador Sea, which would add thousands of kilometres to the journey (as an example, the distance between the Bermuda and the Azores is approximately 3300 km). Unless the Azores constituted an important feeding station during migration, this detour would result in important additional energy expenditure to migrating individuals for no evident advantage. In fact, sei whales are rarely seen feeding in the Azores and satellite telemetry, photo-identification and behavioural studies show that residency time near the islands is short and that whales seldom engage in feeding activity there (this work, Silva *et al. submitted*). In view of that, the more plausible hypothesis is that whales migrating through the Azores in spring/summer originate somewhere south or southeast of the archipelago.

The satellite telemetry data provide a strong indication that the Labrador Sea is an important summering habitat for sei whales migrating through the Azores in the spring and early summer, as all tagged whales moved to that region. These results are further backed by results by Olsen *et al.* (2009), who report on a single sei whale tagged in the Azores in April 2005 that also moved to the Labrador Sea, after visiting the Charlie-Gibb fracture zone.

Additionally, Prieto *et al.* (*submitted*) applied a Bayesian switching state-space model (SSSM; Jonsen *et al.* 2007) to the Argos-derived surface positions estimated with the Least Squares processing algorithm (Anon. 2011) and showed that the behavioural state that can be associated with foraging (Area Restricted Search - ARS) was only detected when the whales were approaching or already in the Labrador Sea. ARS was detected for one individual (80696) during five days while it was still in the warm waters of the NAC. All other ARS bouts were detected after the whales had left the NAC, and most ARS detections (78.5 %, n = 102) were made in the central and northern parts of the Labrador Sea, above 53°N.

Few tags transmitted into late summer, resulting in an incomplete representation of the whales' behaviour during the feeding season. As a result, a possible link between sei whales in the Labrador and in the Iceland-Denmark strait can neither be shown nor ruled out. Nevertheless, two whales (80695, 80717) were apparently heading east of Cape Farewell (southern tip of Greenland) when their signals were lost respectively on June 28 and August 19, 2008.

From the results obtained, it is also difficult to infer the migration route(s) and destination(s) during late summer and autumn. The only whale that was tagged in September moved southeast and it is tempting to draw a line and conclude a link between a presumable wintering area off northwest Africa and the feeding grounds in the Labrador Sea. Although this seems to be a likely possibility, this result needs to be dealt with caution. Firstly, it represents the movements of a single whale. Secondly, it is impossible to know where this whale came from before being tagged. In a scenario of multiple stocks, due to its' position in the central North Atlantic it is conceivable that the Azores is frequented by whales from one stock during the spring migration and from other during late summer and autumn. We find this scenario unlikely but it cannot be ruled out on the basis of data from a single individual.

Sex composition of whales migrating through the Azores

Foetal sex ratio in sei whales is close to 1:1 (Horwood 1987), but differences in gender composition at different locations and seasons can arise as a result of sexual segregation (e. g.: Masaki 1976). A slight excess of males of 8.3% (corresponding to only two additional animals) was recorded in this study, which can be a result of the reduced sample size.

There is an apparent dominance of males in the beginning of the season, even when accounting for the overall difference in sex ratio. That result is surprising in relation to what is known about migration structuring for the species.

In the North Pacific and southern Hemisphere there is compelling evidence that sei whale migration is structured by age class and sex, with pregnant females leading the migration both to and from the feeding grounds, being closely followed by immature/resting males and females, then by mature males and finally by lactating females (Matthews 1938, Gambell 1968, Masaki 1976, Lockyer 1977, Gregr *et al.* 2000, Best and Lockyer 2002). In the North Atlantic the only published indication of structuring during migration was reported for the Irminger Sea (Denmark Strait), with catch data suggesting that large, mature females lead the migration to those feeding grounds (Martin 1983). Nevertheless, these results may partially reflect a hunting bias for larger animals and spatial segregation by sex and age class in the feeding grounds (Martin 1983, Best and Lockyer 2002).

Our results present a pattern that seems incomplete or even inverted, with males apparently leading the migration. Data from both boat and land based surveys indicate that peak sei whale presence in the Azores occurs in April, decreasing therein, with only few sightings reported for March on some years (Silva *et al*. submitted). Thus, our sampling period seems to cover well the occurrence of sei whales in the area.

Best and Lockyer (2002) found that mature females tended to be captured further offshore than immature females and both mature and immature males off the west coast of South Africa (Saldanha Bay). Sei whales in the Azores may show a similar tendency, although the differences in bathymetry and landmass size between the two locations are substantial, which can affect the perception of distance to the shore. This could lead to a lower representation of mature females in our sample, which should be more noticeable in the beginning of the season when most of the pregnant females are expected to pass. On the other hand, Craig and Herman (1997) found gender-related differences in site-fidelity of humpback whales (*Megaptera novaeangliae*) wintering in the Hawaiian Islands. Males were more abundant than females and had a higher rate of return to the Hawaiian breeding grounds. They suggested that part of that difference could be caused by females being less likely than males to conclude the migration to the winter grounds. That could result from part of the immature and resting females spending the winter close to the feeding grounds and some other females, upon becoming pregnant en route to wintering areas, discontinuing their migration to return earlier to the feeding grounds. A similar process could occur with sei whales in the North Atlantic, resulting in a lower abundance of females in the wintering grounds and perhaps causing an excess of males of northbound whales migrating through the Azores in the beginning of the season.

By analysing additional samples already collected and obtaining more samples we expect to increase our sample size in the near future in order to address the gender related questions.

SUMMARY OF CONCLUSIONS AND COMMENTS

When considering the current IWC sei whale stock divisions for the North Atlantic, the only boundary that was not breached by whales tagged in this study was the division between the purported Nova Scotia and Labrador stocks, although one whale (80711) did move close to that boundary, showing that whales of both presumed stocks can co-occur in the area during the feeding season. As a consequence, even if the true stock composition of sei whales cannot be characterized solely from the results presented here, it is clear that the current IWC stock boundaries are not effective in delimitating potential stocks of North Atlantic sei whales.

Our telemetry results point to a complex migration process that can involve longitudinal movements between the two sides of the ocean basin, in addition to the expected latitudinal movements.

Some degree of philopatry to feeding ground(s) seems to exist for the part of the population migrating through the Azores, as whales tagged during three different years (this study, Olsen *et al.* 2009) always headed to the Labrador Sea. Sei whales seen in the Azores occur in aggregations ranging from 2-7 whales and calves have been reported, although in small numbers (Silva *et al.* submitted). Feeding ground philopatry can thus be learned directly from the mother and/or by less experienced animals integrating groups of older animals.

Although caution should be exercised in interpreting the results on seasonal gender distribution, our data suggest a dominance of males in the beginning of the season, which is contrary to data from other regions suggesting that pregnant whales are in the vanguard of the migration. This is possibly a sampling issue, but it could also reflect different behaviour by females during migration both to and from feeding grounds.

REFERENCES

Anonymous, 2011. Argos user's manual. CLS/Service Argos. Unpublished document available through http://www.argos-system.org/documents/userarea/argos_manual_en.pdf. Accession date: July 25 2011.

Belkin, I.M., Levitus, S. 1996. Temporal variability of the Subarctic Front near the Charlie-Gibbs Fracture Zone. *Journal of Geophysical Research* 101(C12): 28317-28324.

Bérubé, M., Palsbøll, P.J. 1996a. Identification of sex in Cetaceans by multiplexing with three *ZFX* and *ZFY* specific primers. *Mol. Ecol.* 5: 283-287.

Bérubé, M., Palsbøll, P. 1996b. Erratum of Identification of sex in cetaceans by multiplexing with three ZFX and ZFY specific primers. *Mol. Ecol.* 5: 602.

Best P.B., Lockyer C.H. 2002. Reproduction, growth and migrations of sei whales *Balaenoptera borealis* off the west coast of South Africa in the 1960s. *So. Afric. Jour. Mar. Sci.* 24: 111–133.

Donovan, G.P. 1991. A review of IWC stock boundaries. *Rep. Int. Whal. Commn.* (special issue) 13:39-68.

Gambell R. 1968. Seasonal cycles and reproduction in sei whales of the southern hemisphere. *Discovery Reports* 35: 31–134.

Gannon, W.L., Sikes, R.S., and the Animal Care and Use Committee of the American Society of Mammalogists. 2007. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. *Jour. Mamm.* 88(3): 809-823.

Gregr E.D., Nichol L., Ford J.K.B., Ellis G., Trites A.W. 2000. Migration and population structure of northeastern Pacific whales off coastal British Columbia: an analysis of commercial whaling records from 1908–67. *Mar. Mam. Sci.* 16: 699–727.

Heide-Jørgensen, M.P., Kleivane, L., Øien, N., Laidre, K.L., Jensen, M.V. 2001. A new technique for deploying satellite transmitters on baleen whales: Tracking a blue whale (*Balaenoptera musculus*) in the North Atlantic. *Mar. Mam.Sci.* 17(4): 949-953.

Horwood J. 1987. *The Sei Whale: Population Biology, Ecology and Management*. Croon Helm, London, UK.

Ingebrigtsen A. 1929. Whales captured in the North Atlantic and other seas. *Rapports et Proces-Verbaux des Reunions. Conseil International pour l'Exploration de la Mer* 56: 1–26.

International Whaling Commission. 2011. *Scientific Committee Report; Annex D: Report of the Sub-Committee on the Revised Management Procedure*. Available from: http://iwcoffice.org/sci_com/screport.htm#report

Jonsen, I.D., Myers, R.A., James, M.C. 2007. Identifying leatherback turtle foraging behavior from satellite-telemetry using a switching state-space model. *Mar. Ecol. Prog. Ser.* 337: 255-264.

Lockyer C. 1977. Some possible factors affecting the age distribution of the catch of sei whales in the Antartic. *Reports of the International Whaling Commission* 1: 63–70. Special issue.

Martin, A. R. 1983. The sei whale off Western Iceland. I. size, distribution and abundance. *Rep. Int. Whal. Commn.* 33: 457-463

Masaki Y. 1976. Biological studies on the North Pacific sei whale. *Bulletin of the Far Seas Fisheries Research Laboratory* 14: 1–104.

Mathews E.A., Keller S., Weiner D.B. 1988. A method to collect and process skin biopsies for cell culture from the free-ranging gray whales (*Eschrichtius robustus*). *Mar. Mam. Sci.* 4: 1–12.

Matthews L.H. 1938. The sei whale *Balaenoptera borealis. Discovery Reports* 17: 183–290.

Mitchell E.D., Chapman D.G. 1977. Preliminary assessment of stocks of northwest Atlantic sei whales (*Balaenoptera borealis*). *Rep. Int. Whal. Commn.* (special issue) 1: 117–120.

Mitchell E.D., Kozicki V.M. 1974 The Sei Whale (*Balaenoptera borealis*) in the Northwest Atlantic Ocean. Paper SC/SP74/32 presented to the IWC Scientific Committee, June 1974 (unpublished). 48pp. + 48 figs. [Available from the Office of this Journal].

Olsen, E., Budgell, W.P., Head, E., Kleivane, L., Nottestad, L., Prieto, R., Silva, M.A., Skov, H., Vikíngsson, G.A., Waring, G., Øien, N. 2009. First satellite-tracked long-distance movement of a sei whale (*Balaenoptera borealis*) in the North Atlantic. *Aqu. Mam.* 35(3): 313-318.

Prieto R., Janiger D., Silva M.A., Waring G.T., Gonçalves J.M. 2011. The forgotten whale: a bibliometric analysis and literature review of the North Atlantic sei whale *Balaenoptera borealis*. *Mam. Rev.* doi: 10.1111/j.1365-2907.2011.00195.x.

Prieto, R., Silva, M.A., Belkin, I:M., Cascão, I., Cruz, M.J., Oliveira, C., Vandeperre, F., Waring, G.T., Gonçalves, J.M. (*Submitted to Deep Sea Research II*) Whales and fronts: The use of frontal systems in the Labrador Sea by sei whales (*Balaenoptera borealis*).

Silva, M.A., Prieto, R., Cascão, I., Seabra, M.I., Machete, M., Baumgartner, M., Santos, R.S. (*Submitted to ICES Journal of Marine Science*). Distribution and relative abundance of cetaceans in the Mid-Atlantic waters around the Azores.

Vikingsson, G.A.; Gunnlaugsson, T.; Pampoulie, C. 2010. A proposal to initiate a pre-implementation assessment of sei whales in the Central North Atlantic. Paper SC/62/RMP2 presented to the IWC Scientific Committee, June 2010 (unpublished). 15pp. [Available from the Office of this Journal].

Table I: Sei whale (*Balaenoptera borealis*) tagging locations and deployment results including tagging date, date of first and last transmissions, days with messages and number of valid positions received.

		Position				Last position Kalman					
ARGOS #	**Tagging date**	**Lat**	**Long**	**First Transmission**	**Last Transmission**	**Lat**	**Long**	**Estimated implant days**	**Period with fixes (days)**	**Delay (days)**	**# fixes Kalman**
80696	26-05-2008	38,22032	-28,45388	08-06-2008	26-07-2008	59,98802	-49,79395	61	48	13	226
80690	02-06-2008	38,34829	-28,48374	18-07-2008	26-09-2008	57,61243	-54,01257	116	70	46	25
80692	06-06-2008	38,42509	-28,53582	14-06-2008	22-06-2008	51,34979	-45,23505	16	8	8	43
80695	07-06-2008	38,43434	-28,60012	07-06-2008	28-06-2008	57,38391	-42,01287	21	21	0	172
80711	02-05-2009	38,36891	-28,5578	02-05-2009	29-06-2009	-53,03486	62,97601	58	58	0	935
80701	15-06-2009	38,25446	-28,52188	19-06-2009	17-07-2009	57,32191	-49,39463	32	28	4	8
80717	17-06-2009	38,44076	-28,72857	17-06-2009	19-08-2009	58,9193	-42,20745	63	63	0	753
80712	21-09-2009	38,63597	-28,98039	09-10-2009	25-10-2009	33,748	-22,886	34	16	18	20

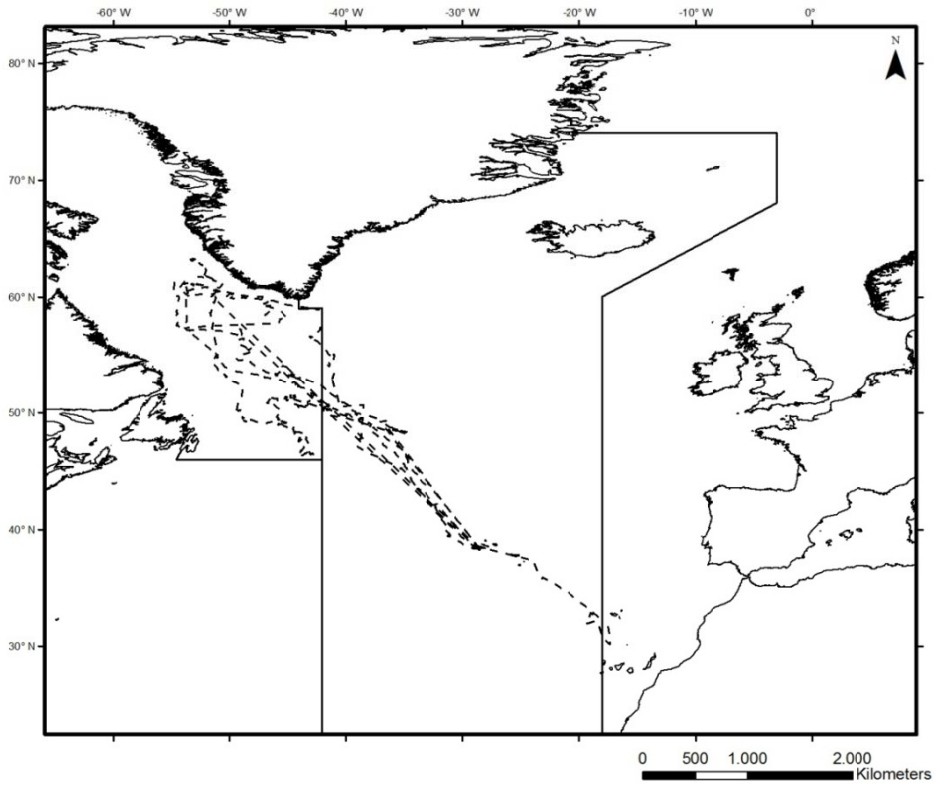

Figure 1: Sei whale tracks of sei whales tagged off the Azores Islands with satellite transmitters. IWC North Atlantic sei whale stock boundaries are shown.

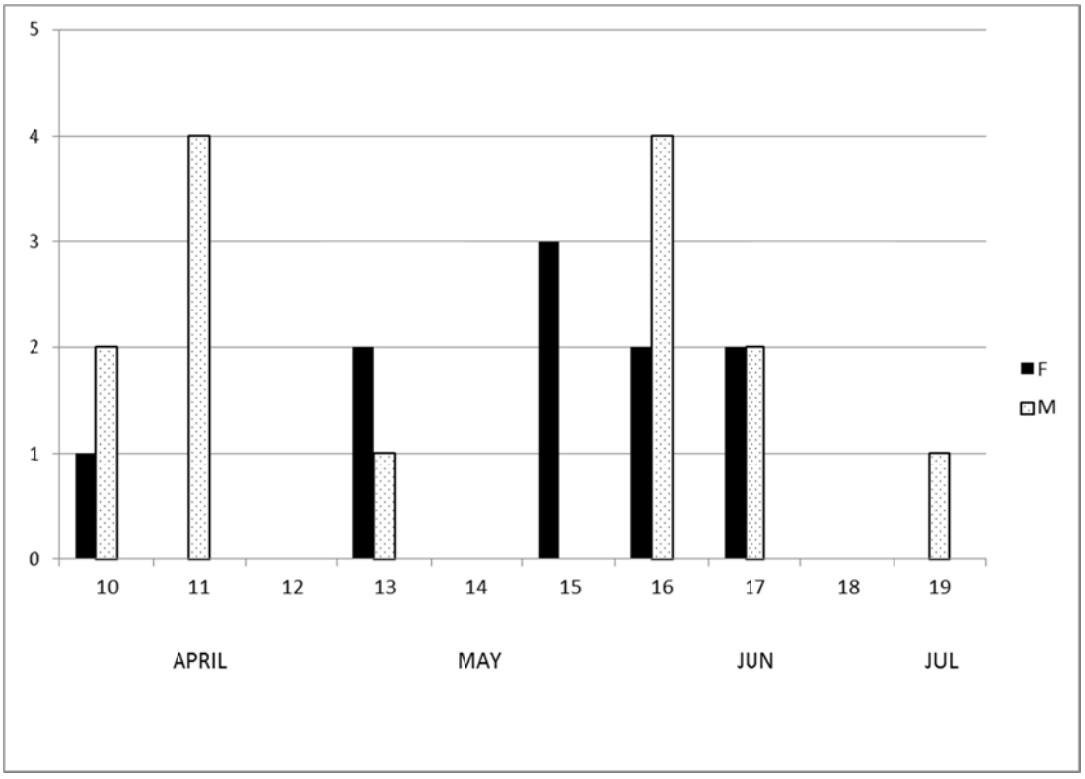

Figure 2: Sex of sei whales biopsy-sampled in the Azores, in relation time of the year; bins correspond to 10 day periods.