Fin Whale (*Balaenoptera physalus*)

1. INTRODUCTION

In the absence of up-to-date published global population assessments for *Balaenoptera physalus* (Fin Whale), *B. borealis* (Sei Whale), and *B. musculus* (Blue Whale), this document provides informal assessments for the purpose of estimating population reduction relative to the A1 criterion for threatened categories. For reasons of space and to avoid repetition across species accounts, the technical details of the population assessments are contained in this supplementary document to the Red List accounts for these taxa. This document should be read in conjunction with the species accounts.

Although the available data do not permit scientifically rigorous estimation of the extent of population reduction, conventional population assessment methods are used to provide a crude indication of the extent of possible reduction for use with the Red List criteria.

The population information for non-Antarctic Blue Whales was found to be too incomplete for an assessment of the kind performed here. Therefore, only Antarctic Blue Whales (*B. musculus intermedia*) were considered.

2. DATA AND METHODS

2.1. Population model

A conventional deterministic age-structured model with an age at first capture ("recruitment") (a_r) and an age at first reproduction (a_m), and linear density-dependence was applied to the North Pacific, North Atlantic and Southern Hemisphere regions separately for each species. The sex ratio of the population and catches is assumed to be 50:50.

Denoting the population of animals aged a in year t as $P_{a,t}$, the equations for the pre-recruit (unexploited) age classes are:

$$P_{a+1,t+1} = S\,P_{a,t} \qquad (a < a_r)$$

where $S = \exp(-M)$ is the annual survival rate. The exploitation rate (the annual fraction of the population that is taken) in year t is given by:

$$E_t = C_t \Big/ \sum_{a=a_r}^{a_m} P_{a,t}$$

where C_t is the historical catch in year t. Age classes from the age at first reproduction onwards are grouped together. The equations for the recruited age classes are:

$$P_{a+1,t+1} \;=\; S\,P_{a,t}\left(1-\;E_t\right) \qquad (a_r \;\le\; a < a_m - 1)$$

$$P_{a_m,t+1} = S\left(P_{a_m-1,t} \;+\; P_{a_m,t}\right)\left(1-E_t\right)$$

The mature population size in the starting year (t = 0) is set to K, the nominal carrying capacity:

$$P_{a_m,0} \;=\; K$$

The values of K in each region were chosen so as to hit the population targets listed in Table 1. The births in year t are given by:

$$P_{0,t} \;=\; R_t P_{a_m,t}$$

where R_t is the reproductive rate in year t. The density-dependent assumption is that R_t is linearly related to the mature population level:

$$R_t \;=\; R_K\left(P_{a_m,t}/K\right) \;+\; R_0\left(1-P_{a_m,t}/K\right)$$

The reproductive rate at carrying capacity is given by:

$$R_K \;=\; (1-S)S^{-a_m}$$

this being the value that yields a zero net population growth rate.

The reproductive rate is related to the population growth rate, r, (in the absence of exploitation) by:

$$R_0 \;=\; \left(1-\frac{S}{1+r}\right)\left(\frac{1+r}{S}\right)^{a_m}$$

2.2 Input parameters

2.2.1 Fin Whales

The last assessments of Fin Whales by the IWC Scientific Committee were conducted in 2016 for the North Atlantic (IWC 2017) and in 1976 for the Southern Hemisphere (Allen 1977; Breiwick 1977). The last assessment for the North Pacific appears to have been in 1974, but few details were recorded (IWC 1975).

The age at first reproduction (AFR) is normally assumed to be 1 yr higher than the age at sexual maturity (ASM). AFR was set to 6 yr in the 2016 North Atlantic assessment by the IWC Scientific Committee, but the origin of that value is mysterious. Gunnlaugsson *et al.* (2013) report an ASM for Fin Whales caught off Iceland of around 8yr during 1965-89, increasing to 14yr during 2006-10, although the sample size in the later years was small. Aguilar *et al.* (1988) estimated 8 yr for the ASM of Fin Whales caught off Spain during 1979-84. Mizroch (1981) estimated 6-7 yr for ASM from Japanese catches in the Southern Ocean during the 1960s and early 1970s, but noted that this value was likely negatively biased due to selection for larger animals. Kimura *et al.* (1958) estimated 8-12 years for ASM for Fin Whales in the North Pacific. For this analysis, the value of 10 yr for AFR (~ 9yr for ASM) from Taylor *et al.* 2007 has been used.

An age at recruitment (age at first capture) of 5 yr was used by Allen (1977) for the Southern Hemisphere, where the catches were mainly pelagic. This value is here for the

Southern Hemisphere and North Pacific, but a value of 3 yr is used for the North Atlantic where the catches were mainly coastal and subject to less size selection (IWC 1992).

In the 2016 North Atlantic assessment, the best fits to the data were obtained using an MSY rate of 4% of the mature population assuming the MSY level at 0.6K (IWC 2017). Assuming a natural mortality rate of 0.04, this corresponds to a maximum rate of increase at low population sizes, ro, of 0.037, which is close to the "default" value of 0.04 assumed for baleen whales when applying the Potential Biological Removal (PBR) criterion for the management of baleen whales under the Marine Mammal Protection Act in the USA (Wade 1998). The 2016 assessment also used a natural mortality rate of 0.08, but it was hard to reconcile this value with the high proportion of older animals in the catch pf recent years (IWC 2017).

In the last southern hemisphere assessment, a value of 0.04 was assumed for the natural mortality rate, and the net recruitment rate was estimated at 0.055 relative to an age at recruitment of 5 yr (Allen 1977); this corresponds to an ro value of approximately 0.045.

The generation time for intermediate population levels (~0.5K) implied by the model used here is 25.5 yr, which is close to the value of 25.9 yr given by Taylor *et al.* (2007). Using the latter value, the three-generation time window for applying the Red List decline criterion A is 1940-2018.

2.2.2 Sei Whales

The last stock assessments of Sei Whales conducted by the IWC Scientific Committee were in 1974 for the North Pacific (IWC 1977) and in 1979 for the Southern Hemisphere (IWC 1980). The Committee is currently (2018) conducting new assessment for the North Pacific but results were not available for this analysis.

For the Committee's assessments, a natural mortality rate of around 0.06 was assumed in both hemispheres (IWC 1977, IWC 1980). The ASM was estimated in the Southern Hemisphere to be around 9 yr (= 10yr for AFR) , similar to the value (AFR = 9yr) estimated by Taylor *et al.* (2007), but possibly to have declined from around 12-13 yr in earlier times. The ASM was estimated to be 9-11 yr by Locker & Martin (1983) in the North Atlantic. The ASM was estimated to be 10yr in the eastern North Pacific (Rice 1977) but about 7yr in the western North Pacific (Masaki 1976). The annual pregnancy rate was estimated to have increased in the Southern Hemisphere, concurrent with the depletion of Sei, Fin and Blue whales, from 0.27 to 0.37-0.39 (IWC 1980, Horwood 1980). Assuming a maximum annual pregnancy rate of 0.40, an AFR of 10 yr, and no additional juvenile mortality, the maximum possible rate of increase is 2.7% per year. Horwood and Millward (1987) also conclude that the maximum rate of increase for Sei Whale populations is less than 3% per year. Newer data on life history parameters have been collected in the northwestern Pacific during 2004-2015 and are awaiting analysis (IWC 2018).

In the Southern Hemisphere, the mean age at recruitment was estimated to be 5 yr for the coastal catches from South Africa, and 8 yr for the pelagic catches (IWC 1980). The mean age at recruitment to the fishery seemed to be quite high (over 10 yr) for the pelagic catches in the North Pacific (Tillman 1977). However, it was probably lower for coastal catches, from which no age data were collected, and for which no minimum size limit was in effect for the earlier years: in later years they were subject to a lower minimum size limit than the pelagic catches. A compromise value of 7 yr is used for the age at recruitment in all oceans for this analysis.

The generation time for intermediate population levels (~0.5K) implied by this model is 22.3yr, close to the value of 23.3 yr given by Taylor *et al.* (2007). Using the latter value, the three-generation time window for applying the Red List decline criterion A is 1948–2018.

2.2.3 Antarctic Blue Whales

The IWC Scientific Committee in 2008 accepted a stock assessment of Antarctic Blue Whales by T. Branch (IWC 2009). However, the assessment is redone here because the IWC/Branch assessment did not include age structure and thus did not estimate the numbers of mature individuals that are required for the IUCN Red List assessment. The catch data have also been updated since then (Allison 2017).

The age at first reproduction is not well-known for Blue Whales in general, but Sears *et al.* (2013) found a youngest age of 11yr for first known calvings of female Blue Whales [n=2] in the eastern North Pacific. Also Rice (1963) reported that females [n=3] attain ASM at 9 to 11 years based on ear plug laminations. This agrees with the estimate of 11yr by Taylor *et al*. (2007) from inter-specific comparisons. The generation time is estimated by Taylor et al. to be 30.8 yr, which corresponds to a 3-generation period from 1926-2018 for application of the A criterion for the Red List.

The only estimates of annual survival rate for Blue Whales are 0.975 for Northwest Atlantic Blue Whales (Ramp *et al*. 2006) or 0.975 for Blue Whales in general (Taylor *et al.* 2007). Therefore, a value of 0.025 was assumed for the natural mortality rate. The mean age at recruitment was taken to be 5 years, as for Fin Whales.

Plausible rates of natural increase for Antarctic Blue Whales, taking into account the age at maturity and reproductive rates have been estimated to be 4.2% p.a. (Branch 2008). Taylor *et al*. (2007) infer an intrinsic increase rate of 5% for Blue Whales and estimate the proportion mature to be 72% for a stable population or 48% for a population increasing at the intrinsic rate. The 5% rate from Taylor *et al*. is used here.

The parameter values used for this assessment are listed in Table 1 for all three (sub)species.

2.3 Catch data

Historic catch data were taken from the IWC catch data base, which includes corrections for all published cases where catch data were found to have been falsified at the time of original submission (Allison, 2017). The biggest corrections were in the southern hemisphere, where Sei Whale catches were underreported by 26,000 whales to avoid declaring catches taken illegally north of the 40°S parallel (the legal northward limit for pelagic whaling in the southern hemisphere), but Fin Whale catches were overreported by 8,000 whales in order to cover for illegal takes of protected or restricted species (Blue, Right and Humpback Whales) (Ivashchenko *et al.* 2011). The correction to the Antarctic Blue Whale catch is smaller, because most of the illegal Blue Whale catches were Pygmy Blue Whales.

Following IWC (2017, Appendix 3 Adjunct 1), a 30% struck-and-lost rate (for whales killed but not landed) was assumed for catches prior to 1916, and unspecified catches were allocated to species in accordance with the species proportions in the nearest block of years of specified catches.

The starting year for the models was the first year of significant exploitation for each species in each basin (Table 1). Each population is assumed to have been at its carrying capacity (K), expressed in terms of mature (reproductive) individuals, in the starting year.

2.4 Population targets

The population targets are listed in Table 1; the basis for them is explained in the species assessments. In some cases they are direct estimates of sums of estimates by area, in others they are rough estimates that take account of incomplete coverage. The initial population sizes by species and ocean basin are tuned to meet the population targets.

3. RESULTS

The resulting population trajectories are shown in Figs 1-3 for Fin Whales, Sei Whales and Antarctic Blue Whales respectively.

For Fin Whales, the estimated world trajectory of mature population size is already above 30% of the 1940 level, but not yet above 50% of the 1940 level. This corresponds to Vulnerable under criterion A1 at the current time.

For Sei Whales, the world trajectory of mature population size is in 2018 closely approaching 30% of the 1948 level; this corresponds to a transition from Endangered to Vulnerable under criterion A1.

Antarctic Blue Whales are estimated to be still at only 2.5% of the 1926 level; this corresponds to Critically Endangered under criterion A1.

Note that the Red List A criterion differs from the status assessment conventionally used for whale population management, the latter being relative to the pre-exploitation population size rather using than the 3-generation window. Both Fin and Sei Whales are estimated to be at about 25% of their pre-exploitation levels. Antarctic Blue Whales are estimated to be at less than 2% of their pre-whaling abundance.

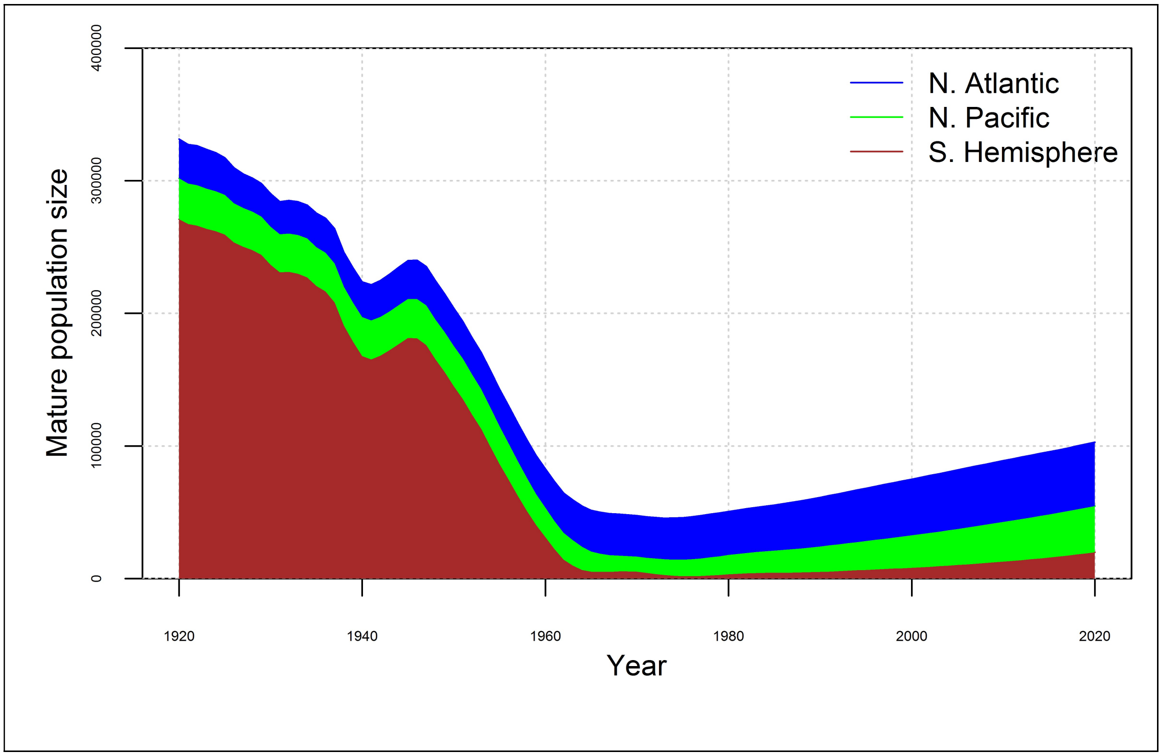

Figure 1. Fin Whales (*Balaenoptera physalus*)

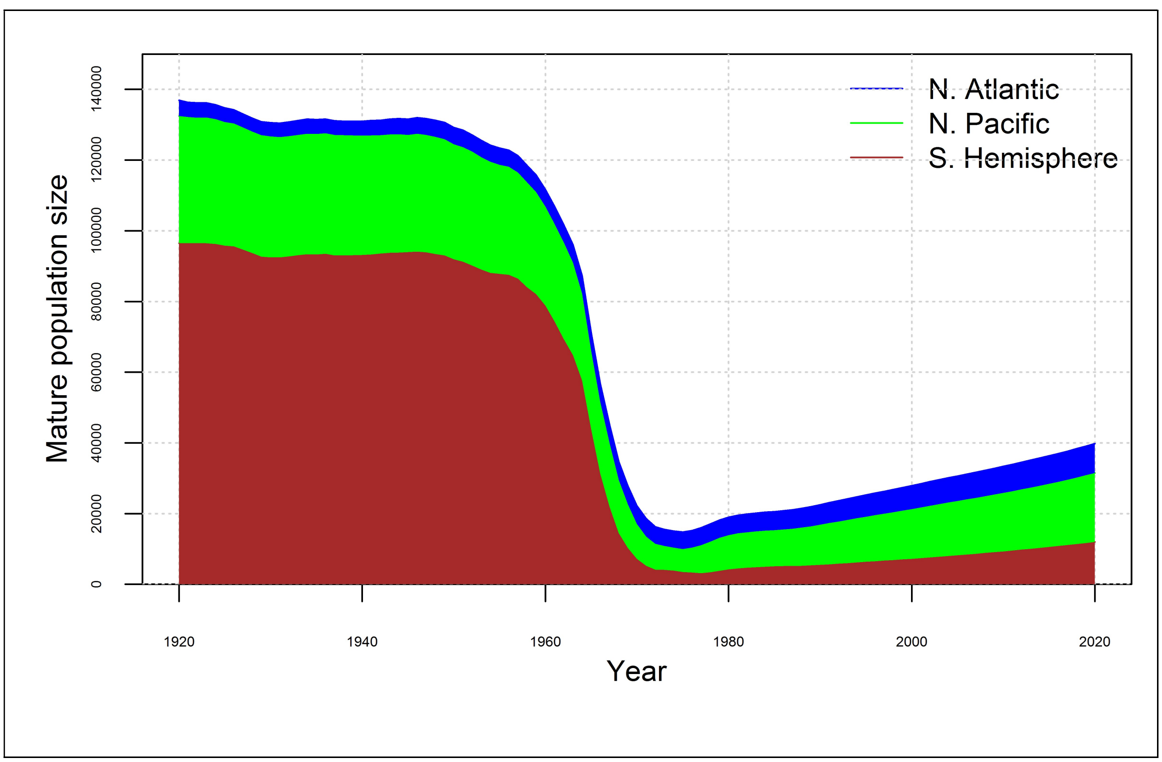

Figure 2. Sei Whales (*Balaenoptera borealis*)

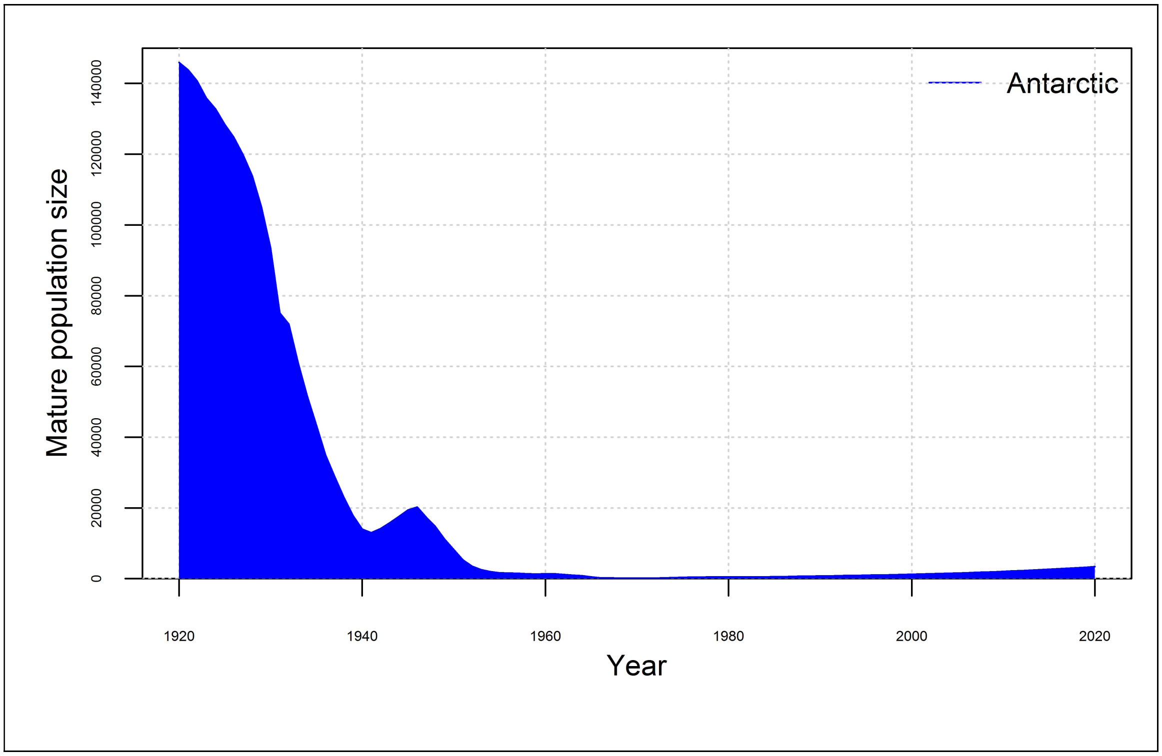

Figure 3. Antarctic Blue Whales (*Balaenoptera musculus intermedia*)

Table 1. Model inputs and results

Species	Ocean	Start year	Natural mortality	Age at recruit-ment	Age at 1st repro-duction	Max. rate of increase	Target pop. size (total)	Target year	Generation time yr	Base year for criteri on A	Matur e pop. in base year	Matur e pop. in 2018	Rati o 2018 pop. to base pop.
Sei	N. Atlantic	1864	0.06	7	10	0.027	11 000	1989					
Sei	N. Pacific	1900	0.06	7	10	0.027	34 000	2011					
Sei	S. Hemisphere	1905	0.06	7	10	0.027	10 000	1983					
Sei	**Global**								**23.3**	**1948**	**131 241**	**38 365**	**0.29**
Fin	N. Atlantic	1864	0.04	3	10	0.037	70 000	2015					
Fin	N. Pacific	1900	0.04	5	10	0.037	50 000	2011					
Fin	S. Hemisphere	1905	0.04	5	10	0.045	25 000	2008					
Fin	**Global**								**25.9**	**1940**	**223 646**	**99 914**	**0.45**
Blue	**Antarctic**	**1905**	**0.025**	**5**	**11**	**0.05**	**2 280**	**1997**	**30.8**	**1926**	**124 737**	**3 064**	**0.025**

REFERENCES

Aguilar, A., Olmos, M. and Lockyer, C. H. 1988. Sexual maturity in fin whales (*Balaenoptera physalus*) caught off Spain. Rep. int. Whal. Commn 38:317-322.

Allen K.R. 1977. Updated estimates of Fin Whale stocks. Rep. int. Whal. Commn 27:221.

Allison C. 2017. The IWC Catch Data Base, version 6.1. (Document and files available from International Whaling Commission www.iwc.int).

Branch, T.A. 2008. Biologically plausible rates of increase for Antarctic blue whales. International Whaling Commission Scientific Committee doc. SC/60/SH8.

Breiwick, J. M. 1977. Analysis of the Antarctic fin whale stock in Area I. Rep. int. Whal. Commn 27:124-129.

Gunnlaugsson Th., Víkingsson G.A. & Halldórsson S.D. 2013. Recent changes in biological parameters of North Atlantic fin whales. IWC Scientific Committee doc. SC/65a/RMP04.

Horwood, J. 1980. Population biology and stock assessment of Southern Hemisphere sei whales. Rep. int. Whal. Commn 30:519-530.

Horwood, J. and Millward, S. 1987. A note on population growth rates. Rep.int. Whal. Commn 37:377-381.

International Whaling Commission. 1975. Report of the Scientific Committee. Rep. int. Whal. Commn 25:62-78.

International Whaling Commission. 1977. Report of the Special Meeting of the Scientific Committee on Sei and Bryde’s Whales. Rep. int. Whal. Commn (Special Issue 1):1-9.

International Whaling Commission. 1980. Report of the Special Meeting on Southern Hemisphere sei whales. Rep. int. Whal. Commn 30:493-505.

International Whaling Commission. 1992. Comprehensive Assessment Special Meeting on North Atlantic Fin Whales, Reykjavík. Rep. int. Whal. Commn 42:595-643.

International Whaling Commission. 2009. Report of the Sub-Committee on Other Southern Hemsiphere Whale Stocks. J. Cetacean Res. Manage. 11(Suppl.):220-247.

International Whaling Commission. 2017. Report of the Subcommittee on the Revised Management Procedure. J. Cetacean Res. Manage. 18(Suppl.):123-173.

International Whaling Commission. 2018. Report of the subcommittee on In-depth Assessments. J. Cetacean Res. Manage. 19(Suppl.):000-000.

Ivashchenko, Y. V., Clapham, P. J., and Brownell Jr., R. L. 2011. Soviet illegal whaling: the devil and the details. Marine Fisheries Review 73: 1-19.

Kimura, S., Nishiwaki, M. and Hibiya, T. 1958. Growth of fin whale in the northern Pacific. Scientific Reports of the Whales Research Institute 13: 97-133.

Lockyer C. & Martin A.R. 1983. The Sei Whale off western Iceland. II. Age, growth and reproduction. Rep. int. Whal. Commn 33:465-476.

Masaki Y. 1976. Biological studies on the North Pacific Sei Whale. Bull. Far Seas Fish. Res. Lab. 14:1-104.

Mizroch S. A. 1981. Analyses of some biological parameters of the Antarctic fin whale (Balaenoptera physalus). Rep. int. Whal. Commn 31:425-434.

Rice, D. W. 1963. Progress report on biological studies of the larger Cetacea in the waters off California. Norsk Hvalfangst-Tidende 52:181-187.

Ramp, C., Bérubé, M., Hagen, W. and Sears, R. 2006. Survival of adult blue whales Balaenoptera musculus in the Gulf of St. Lawrence, Canada. Marine Ecological Progress Report 319: 287-295.

Sears R, Ramp C, Douglas AB, Calambokidis J. 2013. Reproductive parameters of eastern North Pacific Blue Whales Balaenoptera musculus. Endang. Species Res. 22: 23-31 doi: 10.3354/esr00532.

Taylor, B.L., Chivers, S.J., Larese, J. and Perrin, W.F. 2007. Generation length and percent mature estimates for IUCN assessments of Cetaceans. NOAA Southwest Fisheries Science Center, La Jolla, California. Administrative Report LJ-07-01.

Tillman, M. F. 1977. Estimates of population size for the North Pacific sei whale. Rep. int. Whal. Commn (Special Issue) 1:98-106.

Wade P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14(1):1-37.