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Estimating the Maximum Net Productivity Rate for Gray Seals in US waters of the western North Atlantic.

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Introduction:

Gray seals (*Halichoerus grypus*) occur in US coastal waters from New Jersey to the US/Canadian border in Maine. Gray seal abundance in the western North Atlantic was significantly reduced by hunting and the introduction of bounty programs in the 19th and 20th centuries, and were extirpated in the US by the mid-20th century (Wood et al. 2020). Gray seal numbers have been recovering in the US and Canada for over 50 years. Gray seal numbers increased from less than 20,000 animals in the 1960s to over 350,000 animals in 2007 (Bowen et al. 2003; den Heyer et al. 2017, Hammill et al. 2017). The most recent estimate of the number of gray seals in the western North Atlantic is best derived as the sum of Canadian animals in 2016 (424,300 (CV=0.12– Hammill et al. 2017) and US animals in 2016 (27,131 (CV=0.19– Hayes et al. 2019) or 451,431 animals (CV=0.11).

Observed rates of annual recovery for various rookeries or subpopulations have been reported by several authors for this species, including 11% per year by Harding and Harkonen (1999), 12.8% per year by Bowen et al. (2003), and 26.3% per year by Wood et al. (2020). However, it should be noted that Wood et al. concluded that the observed rate of increase at one rookery in US waters was highly influenced by immigration of gray seals from Canadian waters. Recent estimates of the annual rate of increase for the Sable Island population of gray seals are between 4-5% (Hammill et al. 2017). This reduced rate of increase no doubt reflects density dependent effects on the population as it recovers and gets closer and closer to the average carrying capacity for this species.

In the US, the Marine Mammal Protection Act mandates that a limit on annual removals of marine mammals caught incidental to commercial fishing is established. This limit is referred to as the Potential Biological Removal (PBR) level. It is calculated for a given stock as the product of a minimum estimate of abundance (N_{MIN}), 0.5 times R_{MAX} (i.e., the maximum annual rate of increase), and a Recovery Factor (MMPA Sec. 3. 16 U.S.C. 1362; Wade and Angliss 1997). The PBR level is also used to classify fisheries as to the likelihood of their causing mortality and serious injury to a given marine mammal stock (https://www.federalregister.gov/documents/2020/04/16/2020-06908/list-of-fisheries-for-2020). This likelihood is then used in part to prioritize the implementation of observer programs of commercial fisheries in US waters. The PBR level is also used to classify a marine mammal stock as 'strategic' or not, where *inter alia* a strategic stock is one where annual removal rates exceed the PBR level.

There are several ways to calculate R_{MAX} as used in this context, including: (1) use of the maximum annual rate of increase observed during a recovery phase (e.g., Bowen et al. 2003), (2) use of life history data from a recovering population (see Gerrodette and DeMaster, 1990; Hammill et al. 2017), or (3) fitting a suitable density-dependent model to a time series of abundance estimates or indices of abundance. In the implementation of PBR-based management, the National Marine Fisheries Service has adopted a default values of 0.12 and 0.04 for pinniped and cetacean stocks in US waters, respectively. However, circumstances for using stock-specific values for R_{MAX} are detailed in NMFS implementing guidelines (Wade and Angliss 1977; NMFS 2016; see Appendix A).

The purpose of this short report is to provide an estimate of R_{MAX} for gray seals based on fitting a discrete logistic model to a time series of pup counts from Sable Island (published by Hammill et al. 2017), and then converting the estimated continuous rate of increase to a discrete value (which is used by NMFS in PBR threshold calculations).

Methods:

The population dynamics model and estimation scheme

The population dynamics are governed by a continuous logistic model, i.e.:

$$N_{y+1} = N_y + rN_y(1 - N_y / K) \tag{1}$$

where N_y is the number of animals (pups) in year *y*; *K* is carrying capacity; and *r* is the intrinsic rate of growth. The estimates of abundance are assumed to be normally distributed about their expected values, leading to a likelihood of the form:

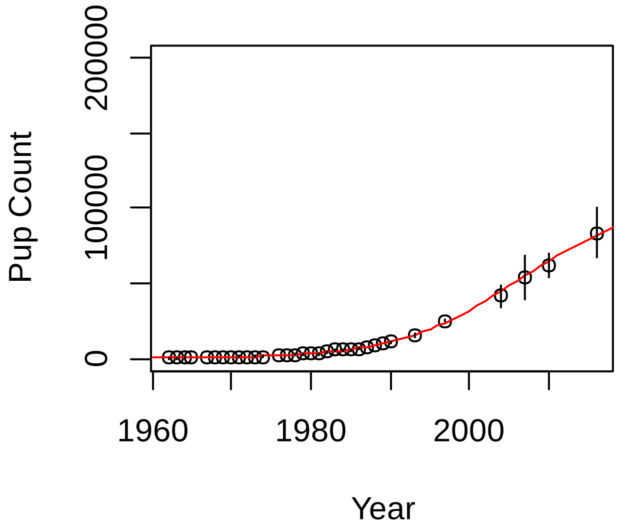
$$L = \prod_{y \in y^*} \frac{1}{\sqrt{2\pi}\sigma_y} e^{-(N_y - N_y^{obs})^2/(2\sigma^2)} \tag{2}$$

where y^* is the set of years with estimates of abundance; N_y^{obs} is the estimate of abundance for year *y*; and σ_y is the standard deviation of N_y^{obs}. The values for σ_y are set to actual standard deviations for 1993 onwards and to an estimated value (σ^*) for the years prior to 1992. The analysis therefore involves estimating four parameters (*r*, log *K*, $\log \sigma^*$, and N_{1962}).

The data were published by Hammill et al. 2017 for Sable Island pup production from 1962-2016.

Results

The model fits the data very well (see below)



The estimates of the parameters of the model are:

Parameter	Estimate (SD)
R	0.141 (0.003)
log$K$	11.49 (0.108)
$\log \sigma^*$	5.632 (0.140)
N_{1962}	306 (22.4)

The current (2020) estimate is 89,761 which is 92.2% of the estimate of carrying capacity.

Discussion:

The maximum rate of increase for a given stock of marine mammals is used to estimate the threshold for annual removals of that stock by commercial fisheries in US waters. As noted, the PBR is directly proportional to the R_{MAX} value. Hayes et al. (2019) used the default value of 12% for R_{MAX}. Based on the analysis we have presented here, we recommend that NMFS use a value of 14.1% for the value of R_{MAX} used to estimate PBR for gray seals in US waters. This value is approximately 17% greater than the default value. A sensitivity test based on modelling the pup counts using a continuous logistic model and converting the resulting estimate of the continuous rate of increase to a discrete rate also led to an estimate of 14.1%.

It should be noted that fitting an exponential model to a time series of population indices (e.g., pup counts) is not recommended as the optimal method for calculating R_{MAX}, where there is evidence that the rate of increase is being diminished by the effects of density dependence.

Literature Cited

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Appendix A.

From GAMMS II (NMFS 2016). *"To be consistent with a risk-averse approach, these default values should be near the lower range of measured or theoretical values (or 0.12 for pinnipeds and sea otters and 0.04 for cetaceans and manatees). Substitution of other values for these defaults should be made with caution, and only when reliable stock-specific information is available on* R_{max} *(e.g., estimates published in peer-reviewed articles or accepted by review groups such as the MMPA Scientific Review Groups or the Scientific Committee of the International Whaling Commission)."*