# Analytical reference points for data-limited Carcharhinid sharks

## Introduction

* Why care about sharks/reef sharks?
  + Sharks are being overexploited on a global level (Worm et al., 2013)
  + Shark fisheries have long been important at local, regional, and international scales from social, cultural, and economic perspectives. (Dulvy et al., 2017)
  + “The last decade has seen growing global concern about the status of elasmobranch populations, particularly due to their intrinsic sensitivity to fishing impacts and their very low population growth rates (Dulvy et al. 2014)”.
  + Inherently more vulnerable to fishing than other kinds of fishes
  + Reef shark populations are collapsing, because of illegal fishing, because rarely subject to specific limits on fishing pressure (Robbins et al., 2006)
  + coastal shark populations in the Atlantic have declined by as much as 85% in the past two decades (Camhi, 1999; Baum et al., 2003).
  + Loss of apex predators on reefs may result on damaging trophic cascades (Bascompte et al., 2005)
  + Reef sharks therefore merit greater research attention to underpin science-based management and conservation action
* Why are sharks hard to assess/study?
  + chondrichthyan fishes are a particularly data limited group (Barker & Schuessel 2005.. others), which explains why most stocks worldwide have not been assessed with formal fisheries stock assessment methods (Cortés et al., 2012)
  + ‘Stock assessments take money and expertise (Geromont and Butterworth, 2015) which developing countries usually cannot afford’ (Evans, 2000) better reference for this?
* Why use age-structured catch-free analytical methods to find sustainability reference points?
  + ‘In fisheries where there is a high degree of uncertainty in reported catches, or catches are not reported at all, stock assessment models that rely on catch data may not be appropriate. For numerous shark species there is uncertainty about the magnitude of commercial and recreational catches, in part due to identification problems’ (Cortés et al., 2006)
  + Fishery-dependent data can be unreliable for sharks, as they are hard to identify and are often not the target species (Baum et al., 2003; Burgess et al., 2005; Clarke and Hoyle, 2014; Harry et al., 2016)
  + estimation of reference points is a key step in determining stock status (Clarke and Hoyle, 2014; Cortés and Brooks, 2018) other source?
  + The population growth rate of many shark species has been overestimated in the past because of the assumption that all juveniles survive to maturity (Pardo et al., 2016). Using age-structured survivorship data addresses that problem
* Why use life history traits to find reference points?
  + Life history traits related to body size, growth, age and reproduction are known to be correlated with each other (Cortés, 2000; Hutchings et al., 2012) and thus may be use to predict related parameters such as rate of intrinsic increase or lifetime reproductive output (Frisk et al., 2011; Jennings et al., 1998; Reynolds et al., 2005)
  + ‘the most fundamental parameter in population biology is the reproductive rate at low population size (ã)’. … It is ‘central to calculating r (population growth), reference points, and estimation of long term anthropogenic impacts (Myers et al., 1999)
  + Body size and age at maturity can be used to predict Rmax (Hutchings et al., 2012)
* Why use modelling to predict unknown life history traits ?
  + Life history traits, while more commonly available than catch data, are still not available for many of the more obscure species which are for example, of less commercial interest or occur in lower-income countries
  + Shark stock assessments often borrow data from similar species/use species complexes because there is not enough species-specific data available (NMFS, 2006)
* In this paper…
  + I will do this this and this analysis, producing these results
  + I will focus on a group of species which are understudied, even in the shark world, but nevertheless urgently require science-based management and conservation action
  + Risk Assessment methods (such as estimating reference points with life history data) for elasmobranchs has lagged behind that of other vertebrate groups (Cortés et al., 2015), therefore this paper fills a hole in the literature
  + Sustainable shark fishing is feasible with the right scientific underpinning (Simpfendorfer and Dulvy, 2017) so we should strive to achieve that end…this paper contributes…

## Methods

* It’s ok to calculate parameters you don’t have based on known relationship to parameters you do have, based on previous empirical work (Kacev et al., 2017)
* Previous studies have also used data from better-studied species to model life history parameters of data-poor shark species (Jiao et al., 2011) robin hood approach (Kacev et al., 2017)
* Bayesian hierarchical methods are great for data-poor species bc they allow you to borrow strength from species with good-quality data (Jiao et al., 2011)

Part 1: Data Collection

1. Age-structured maturity data
   1. Stock assessments
   2. Papers
2. Trait covariates
   1. How chose candidate traits – papers describing relationships between shark or fish maturity and related factors.
   2. How collected candidate traits
      1. fishbase
      2. shark traits
      3. shark refs
      4. google scholar

Part 2: Modelling

We developed a Bayesian hierarchical model to quantify the relationship between Carcharhinid maturity ogives and candidate life history variables at the family and at the stock scale. Maturity ogives are specified by two variables *a50* and *s* (equation 1), where *a* isage, *a50* is the age at which 50% of a population of sharks achieves sexual maturity, and *s* describes the steepness of the ogive (ref).

Both response variables were described using Normal distributions and were estimated simultaneously as two levels within the same model. The distribution of *a50* values were defined by a mean *Ga50* and a standard deviation Ϭa50 (equation 2). *Ga50* was described as a Uniform distribution and allowed to vary between 0 and 30, as the range of known Carcharhinid ages at maturity are 1 and 21 (FishBase2020). Ϭa50 was described using an Exponential distribution decaying from 1.

The distribution of steepness values was defined by a mean *Gs* and a standard deviation *Ϭs* (equation 6). The mean values of *S* where described using a Uniform distribution and allowed to vary between 0.01 and 10, meaning all curves must describe an increasing % maturity as age increases but can do so at different rates.

Possible maturity ogives described by the null model and priors were visualised using prior predictive simulation (figure 1)

Chart

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Covariates were applied at the level of *Ga50* and *Gs* as shown in equations 9 and 10.

Xx Life history traits were initially related to a50 and S because of previous research investigating various relationships between shark growth and other aspects of ecology and life history (go into more detail here, run through the papers cited in list of model params).

Explain how initial list of covariates was refined down to final list

* + - * + Ran a series of model versions
        + Removed covariates with no effect
        + Ran models with S and a50 separately

Summary table of input data? With candidate and chosen covariates, sources for mat data

The outcome space defined by these prior distributions combined with age-structured maturity data and related life history traits was sampled using a Hamiltonian Markov Chain Monte Carlo sampler. Modelling was carried out in Python using the PyMC3 package. Model performance was assessed by looking at convergence (Gelman-Ruben’s R-hat statistic), and through examining posterior traces for full exploration of the potential outcome space. Model fit was evaluated using Widely Acceptable Information Criterion (WAIC) and by plotting observed maturity values against the posterior distribution of maturity ogives.

Predicted Ogives:

* Describe prediction method
* Describe process of assessing results

# Results

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Chart, scatter chart

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Chart, box and whisker chart

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# Chart Description automatically generatedChart, histogram Description automatically generated

Chart, histogram

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# Discussion

* Why some of the out of sample results don’t work – what traits do tigers have e.g.g that make them hard to predict?

# References

Bascompte, J., Melián, C.J., Sala, E., 2005. Interaction strength combinations and the overfishing of a marine food web. Proc. Natl. Acad. Sci. U. S. A. 102, 5443–5447. https://doi.org/10.1073/pnas.0501562102

Baum, J.K., Myers, R.A., Kehler, D.G., Worm, B., Harley, S.J., Doherty, P.A., 2003. Collapse and Conservation of Shark Populations in the Northwest Atlantic. Science (80-. ). 299, 389–392. https://doi.org/10.1126/science.1079777

Brooks, E.N., Powers, J.E., Cortés, E., 2010. Analytical reference points for age-structured models: Application to data-poor fisheries. ICES J. Mar. Sci. 67, 165–175. https://doi.org/10.1093/icesjms/fsp225

Burgess, G.H., Beerkircher, L., Cailliet, G.M., Carlson, J.K., Cortés, E., Goldman, K.J., Dean Grubbs, R., Musick, J.A., Musyl, M.K., Simpfendorfer, C.A., 2005. Is the collapse of shark populations in the Northwest Atlantic Ocean and Gulf of Mexico real? Fisheries 30, 19–26.

Clarke, S.C., Hoyle, S., 2014. Development of Limit Reference Points for Elasmobranchs. Majuro.

Cortés, E., 2000. Life History Patterns and Correlations in Sharks. Rev. Fish. Sci. 8, 299–344. https://doi.org/10.1080/10408340308951115

Cortés, E., Brooks, E.N., 2018. Stock status and reference points for sharks using data-limited methods and life history. Fish Fish. 19, 1110–1129. https://doi.org/10.1111/faf.12315

Cortés, E., Brooks, E.N., Apostolaki, P., Brown, C.A., 2006. Stock Assessment of Dusky Shark in the US Atlantic and Gulf of Mexico. Panama City.

Cortés, E., Brooks, E.N., Gedamke, T., 2012. Population Dynamics, Demography and Stock Assessment, in: Carrier, J.C., Musick, J.A., Heithaus, M.R. (Eds.), Biology of Sharks and Their Relatives. CRC Press, Boca Raton, p. 633.

Cortés, E., Brooks, E.N., Shertzer, K.W., 2015. Risk assessment of cartilaginous fish populations. ICES J. Mar. Sci. 72, 1057–1068. https://doi.org/10.1093/icesjms/fss153

Dulvy, N.K., Simpfendorfer, C.A., Davidson, L.N.K., Fordham, S. V., Bräutigam, A., Sant, G., Welch, D.J., 2017. Challenges and Priorities in Shark and Ray Conservation. Curr. Biol. 27, R565–R572. https://doi.org/10.1016/j.cub.2017.04.038

Evans, D.W., 2000. The Consequences of Illegal, Unreported and Unregulated Fishing for Fishery Data and Management. Rome.

Frisk, M.G., Miller, T.J., Fogarty, M.J., 2011. Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. Can. J. Fish. Aquat. Sci. 981, 969–981. https://doi.org/10.1139/cjfas-58-5-969

Geromont, H.F., Butterworth, D.S., 2015. Complex assessments or simple management procedures for efficient fisheries management: a comparative study. ICES J. Mar. Sci. 72, 262–274.

Harry, A. V., Saunders, R.J., Smart, J.J., Yates, P.M., Simpfendorfer, C.A., Tobin, A.J., 2016. Assessment of a data-limited, multi-species shark fishery in the Great Barrier Reef Marine Park and south-east Queensland. Fish. Res. 177, 104–115. https://doi.org/10.1016/j.fishres.2015.12.008

Hutchings, J.A., Myers, R.A., García, V.B., Lucifora, L.O., Kuparinen, A., 2012. Life-history correlates of extinction risk and recovery potential. Ecol. Appl. 22, 1061–1067. https://doi.org/10.2307/41416769

Jennings, S., Reynolds, J.D., Mills, S.C., 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. B Biol. Sci. 265, 333–339. https://doi.org/10.1098/rspb.1998.0300

Jiao, Y., Cortés, E., Andrews, K., Guo, F., 2011. Poor-data and data-poor species stock assessment using a Bayesian hierarchical approach. Ecol. Appl. 21, 2691–2708.

Kacev, D., Sippel, T.J., Kinney, M.J., Pardo, S.A., Mull, C.G., 2017. An Introduction to Modelling Abundance and Life History Parameters in Shark Populations, in: Larson, S.E., Lowry, D. (Eds.), Advances in Marine Biology Vol. 78. Academic Press, Oxford, pp. 45–87. https://doi.org/10.1016/bs.amb.2017.08.001

Myers, R.A., Bowen, K.G., Barrowman, N.J., 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56, 2404–2419. https://doi.org/10.1139/f99-201

NMFS, 2006. SEDAR 11: Stock assessment report - large coastal shark complex, blacktip, and sandbar shark, SEDAR 11. Silver Spring, Maryland.

Pardo, S.A., Kindsvater, H.K., Reynolds, J.D., Dulvy, N.K., 2016. Maximum intrinsic rate of population increase in sharks, rays, and chimaeras: the importance of survival to maturity. Can. J. Fish. Aquat. Sci. 73, 1159–1163. https://doi.org/10.1139/cjfas-2016-0069

Reynolds, J.D., Dulvy, N.K., Goodwin, N.B., Hutchings, J.A., 2005. Biology of extinction risk in marine fishes. Proc. R. Soc. B Biol. Sci. 272, 2337–2344. https://doi.org/10.1098/rspb.2005.3281

Robbins, W.D., Hisano, M., Connolly, S.R., Choat, J.H., 2006. Ongoing Collapse of Coral-Reef Shark Populations. Curr. Biol. 16, 2314–2319. https://doi.org/10.1016/j.cub.2006.09.044

Simpfendorfer, C.A., Dulvy, N.K., 2017. Bright spots of sustainable shark fishing. Curr. Biol. 27, R97–R98. https://doi.org/10.1016/j.cub.2016.12.017

Worm, B., Davis, B., Kettemer, L., Ward-Paige, C.A., Chapman, D.D., Heithaus, M.R., Kessel, S.T., Gruber, S.H., 2013. Global catches, exploitation rates, and rebuilding options for sharks. Mar. Policy 40, 194–204. https://doi.org/10.1016/j.marpol.2012.12.034

Figures

Tables