Population viability analysis of smalltooth sawfish in the United States

John K. Carlson
NOAA Fisheries
Sustainable Fisheries Division
Highly Migratory Species Branch

Overview-why are smalltooth sawfish listed on the ESA?

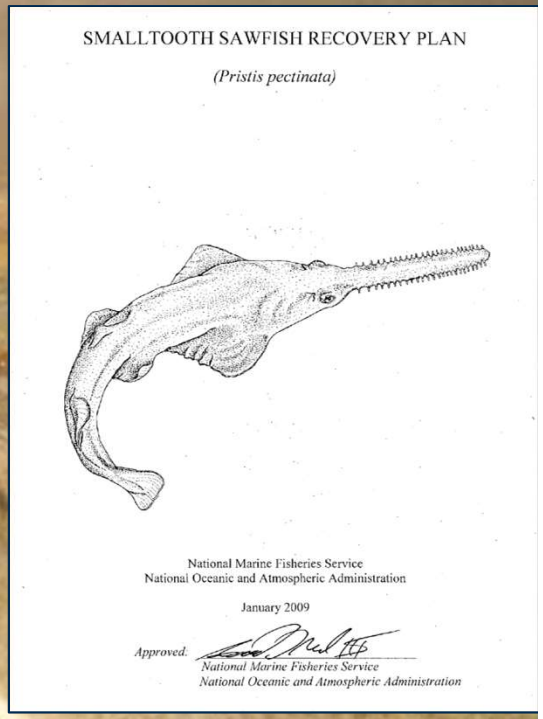
- ✔ In US, smalltooth sawfish once ranged from mid-Atlantic states to the Florida Keys and throughout Gulf of Mexico
- ✔ By late 1990s, range contracted to southwest Florida

From Burgess et al. (2011)

- ✔ Range contraction between 90-95% and significant reduction in encounter records due to habitat loss and fishing mortality
- ✔ US population listed as “Endangered” on ESA in 2003
  - ✔ Recovery plan published in 2009
  - ✔ Critical habitat finalized in 2009

Smalltooth sawfish recovery plan

- Published in 2009
  - Recovery objectives:
    - *Identify, protect and/or restore smalltooth sawfish habitats*
    - *ensure smalltooth sawfish abundance increases substantially and the species reoccupies areas from which it had been previously extirpated*
    - *minimize human interactions, and associated injury and mortality*
      - ***Use population viability analysis (PVA) or other types of population models to evaluate the effect of fishery takes on the species' viability***.


SMALLTOOTH SAWFISH RECOVERY PLAN

(Pristis pectinata)

National Marine Fisheries Service
National Oceanic and Atmospheric Administration

January 2009

Approved:
National Marine Fisheries Service
National Oceanic and Atmospheric Administration

Population Viability Analysis

Population viability analysis (PVA) is a modeling tool that estimates the future size and risk of extinction for populations of organisms

-predict the probability of the population persisting into the future

-useful tool to explore potential consequences of management actions in the light of uncertain data and an ambiguous future

A wide range of modeling approaches are used in PVA, from simple models based on abundance trends to complex individual-based habitat models

Given the limited data for smalltooth sawfish, a Leslie matrix approach was utilized using inputs of reproduction and survivorship was utilized

Original Population Viability Model

- ✔ **Modeling productivity and time to recovery**
  - ✔ Recovery plan originally predicted recovery to take 100 years
    - ✔ Initial information on life history was limited
    - ✔ Developed for female proportion of population

AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. (2014)
Published online in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2434

Recovery potential of smalltooth sawfish,* Pristis pectinata, *in the United States determined using population viability models

JOHN K. CARLSON[a,*] and COLIN A. SIMPFENDORFER[b]
[a]*National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City, FL, USA*
[b]*Centre for Sustainable Tropical Fisheries and Aquaculture & School of Earth and Environmental Sciences, James Cook University, Townsville, Queensland, Australia*

ABSTRACT

1. Determining the recovery potential of endangered species is an important component for developing strategies necessary to return populations to healthy levels. Many species of endangered marine animals have been regarded as having low productivity and therefore, an inherent inability to rapidly recover from severe depletion.
2. An age-structured Leslie matrix model was constructed for the US population of smalltooth sawfish, *Pristis pectinata*, to determine their ability to recover under scenarios using different life history inputs and the effects of bycatch mortality and catastrophes.
3. Population growth was highest (λ=1.237 yr^{-1}) when age-at-maturity was 7 yr and decreased to 1.150 yr^{-1} when age-at-maturity was 11 yr.
4. Despite a high level of variability throughout the model runs, in the absence of fishing mortality or climate catastrophic effects the population grew at a relatively rapid rate approaching carrying capacity in 40 or 50 yr when the initial population was 600 or 2250 females, respectively. Population projections under various levels of fishing mortality resulted in extinction when mortality was highest, initial population size was small, and age-at-maturity was 11 yr. Scenarios testing the potential effects of extreme cold exposure showed little difference to those scenarios testing the effects of fishing mortality.
5. Using the optimistic estimates of population size, lower age-at-maturity and the lower level of fisheries-related mortality, smalltooth sawfish in US waters appear to have the ability to recover within the foreseeable future. Effective management and recovery of this species can only be achieved by keeping fishing-related mortality low.

Received 22 March 2013; Revised 26 September 2013; Accepted 23 November 2013

KEY WORDS: elasmobranch; conservation; extinction risk; Leslie matrix; productivity

INTRODUCTION

Determining the recovery potential of endangered species is an important component for developing strategies necessary to return populations to healthy levels. Many species of endangered marine animals have been regarded as having low productivity and therefore, an inherent inability to

*Correspondence to: J.K. Carlson, National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City Laboratory, Panama City, Florida, USA, 32408. E-mail: john.carlson@noaa.gov

Parameter	Value	Source
Age-at-maturity:	7 years 11 years	Simpfendorfer (2005) Carlson (unpublished data)
Maximum age:	30 years	Schaerer et al. (2012)
Litter size:	3.1 female pups per year (0.758)	Bigelow and Schroeder (1953) Simpfendorfer (2005) Carlson (unpublished data)
Survivorship:		
Age 0	0.87 (0.208)	Multiple invariant methods
Age 1	0.87 (0.131)	(e.g. Hoenig (1983); Pauly (1980); Chen and Watanabe (1989); Peterson and Wroblewski (1984) Lorenzen (1996)
Age 2	0.89 (0.104)	
Age 3	0.90 (0.093)	
Age 4	0.91 (0.087)	
Age 5-6	0.92 (0.082)	
Age 7-11	0.93 (0.080)	
Age 12-30	0.94 (0.080)	

NOAA FISHERIES

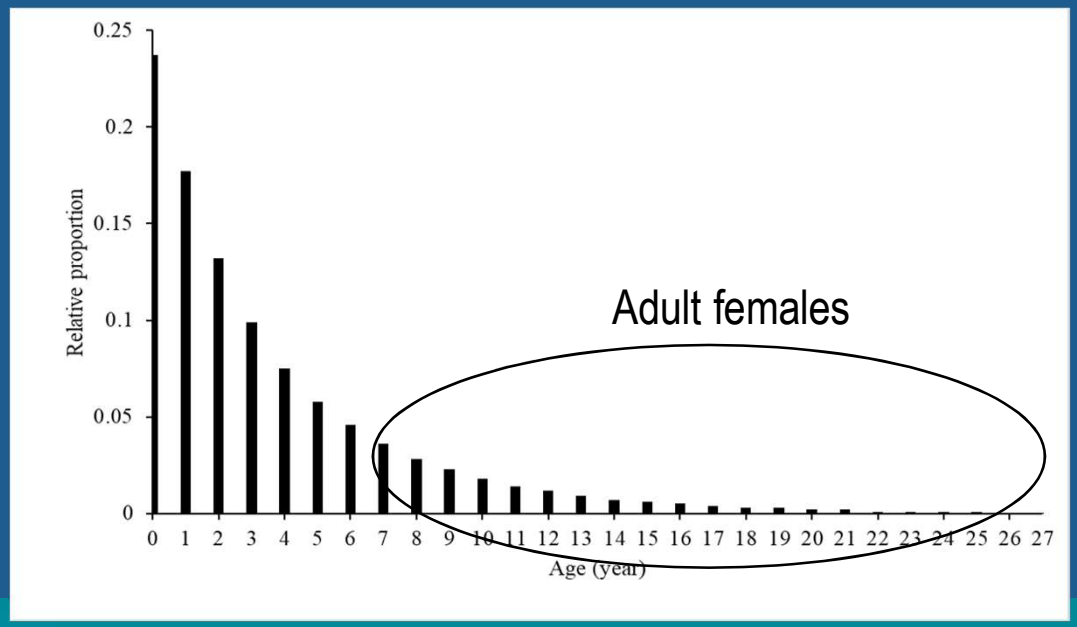
Original Population Viability Model

✔ Sources of mortality

- ✔ Three fishery sources identified
  - ✔ Commercial shark bottom longline
  - ✔ Recreational rod and reel
  - ✔ Commercial shrimp trawl fishery

Original Population Viability Model

- ✔ Initial population size
  - ✔ No census population size
    - ✔ Based on encounter data, 0.151 sawfish km/2 (Wiley and Simpfendorfer, 2010) applied to critical habitat area (1:1 sex ratio)
      - ✔ 600 female population
    - ✔ Chapman et al. (2011) estimated the effective genetic population size (Ne)
      - ✔ Ne can be defined as the number of potential parents contributing their genes to the next generation
      - ✔ For smalltooth sawfish = ~300 adults (1:1 sex ratio)



Original Population Viability Model

- ✔ Designed to determine sawfish capability to recover under various scenarios of the major threats
- ✔ An age-structured Leslie matrix model using data in the form of a pre-breeding census with inputs of fecundity and survivorship
- ✔ Depending on age of maturity smalltooth sawfish have moderate productivity based on a comparison study by Cortes (2016)

Leslie Matrix

$$L = \begin{bmatrix} F_0 & F_1 & F_2 & F_3 \\ S_0 & 0 & 0 & 0 \\ 0 & S_1 & 0 & 0 \\ 0 & 0 & S_2 & 0 \end{bmatrix}$$

Original Population Viability Model

- The population was projected forward for 100 yr for each scenario. Stochasticity was incorporated by randomly drawing values specified in the Leslie matrix and replicating each time step 500 times.

RESULTS

- Despite a high level of variability, in the absence of fishing mortality the population grew at a relatively rapid rate approaching carrying capacity in 40 or 50 years when the initial population was 600 or 2,250 females, respectively
- Population projections under various levels of fishing mortality resulted extinction when mortality was highest, initial population size was small, and age-at-maturity was 11 years
- Using the optimistic estimates of population size, lower age-at-maturity and the lower level of fisheries-related mortality, smalltooth sawfish in US waters appear to have the ability to recover within the foreseeable future

Updated Population Viability Model

- ✔ Since Carlson and Simpfendorfer (2015), new information has been made available on life history, genetic population size and threats.
  - ✔ Refined estimates of fecundity
  - ✔ Better data on maturity from necropsies and hormonal analysis
  - ✔ New analysis on fishery threats
    - ✔ Graham et al. (2022) determined bycatch risk associated with the US southeast shrimp trawl fishery was significantly higher than all other fisheries assessed
  - ✔ Updated estimates on genetic population size

Global Ecology and Conservation

Trouble in the trawls: Is bycatch in trawl fisheries preventing the recovery of sawfish? A case study using the US population of smalltooth sawfish, *Pristis pectinata*

John K. Carlson

Updated Population Viability Model

- ✔ All species are classified as highly threatened with extinction. Critically Endangered following IUCN criteria
- ✔ Threats are similar globally to all 5 species
- ✔ Carlson (2023) study was designed as a "case study" to inform how other sawfish species have the ability to recovery

Page 1 of 2 Oryx - The International Journal of Conservation

Conservation news

Sawfish move closer to extinction, but positive signs are emerging

In November 2021, the IUCN Species Survival Commission Shark Specialist Group held a series of online workshops to reassess the IUCN Red List of Threatened Species™ extinction risk status of the world's five sawfish species (family Pristidae). This process concluded in December 2023 with the publication of the final Red List assessment for the Narrow Sawfish, *Anoxypristis cuspidata*.

Since the previous assessments (conducted in 2012), sawfish populations have continued to face severe, ongoing threats globally from fishing and habitat loss, and collectively their status has worsened. Previously, three species were listed as Critically Endangered and two species as Endangered. With the current uplisting of the Narrow Sawfish and Dwarf Sawfish, *Pristis clavata*, all sawfish species are now in the highest Red List threat category of Critically Endangered. Based on the available evidence, population size reduction ≥ 80% was inferred or suspected over the last three generations due to 1) a decline in their extent of occurrence and habitat quality, and 2) potential levels of exploitation, and that the causes of this reduction have not ceased. The outcomes of these latest assessments are disheartening and a further reminder that continued actions to reduce mortality and protect critical habitats are urgently needed to prevent sawfish from going extinct.

Despite their dire status, some positive signs can be taken from new information gathered during the reassessments. Several regions continue to act as 'lifeboats' for some sawfish species, including parts of northern Australia and Papua New Guinea. Additionally, there is strong evidence that Smalltooth Sawfish, *P. pectinata*, are beginning to recover in Florida waters (United States) after two decades of sustained conservation efforts.

The past decade has also seen a vitally needed shift in sawfish conservation, a sign that a Global Conservation Strategy released in 2014 may be working (Yan et al, 2021, *Science Advances*, 7, 7). From relative obscurity, sawfish have moved into the conservation spotlight, with the emergence of several dedicated conservation initiatives, non-government organisations, directed funding, and research programs. This was reflected in the size and geographic diversity of the Red List reassessment team that comprised 61 individuals from 25 nations.

Work over the last decade has helped provide a much clearer picture of the current distribution of sawfishes globally including in many poorly surveyed areas. This has led to the identification of sites where sawfishes continue to persist, amid intense pressure, such as in Bangladesh, Sudan, and parts of Central America. Grass roots conservation initiatives in these areas are leading to increased reports of sawfish being released alive as a result of education and outreach programs. These types of

Harry et al. (2023)

http://www.oryxthejournal.org

Targeted fishing and bycatch

Species	Residential and commercial development	Energy production and mining	Transportation and service corridors	Natural system modifications	Pollution	Climate change and severe weather	Biological resource use
Largetooth Sawfish *Pristis pristis*							
Smalltooth Sawfish *P. pectinata*							
Green Sawfish *P. zijsron*							
Dwarf Sawfish *P. clavata*							
Narrow Sawfish *Anoxypristis cuspidata*							

Yan et al. (2021)

Updated Population Viability Model

- ✔ Initial population size
  - ✔ New analysis by Smith (2021); Ne=650
  - ✔ Some studies of sharks suggest Ne approximates Nc (census size) (ratios 0.7-0.8) or ~0.4 for sawfish (Smith 2021)
    - ✔ Assumed two scenarios
      - Ratio 0.7-0.8 (average of sandbar, grey nurse and zebra shark)
      - Ratio ~0.4 Smith (2021)
  - ✔ Density of the the number of breeders (Nb)
    - ✔ Charlotte Harbor=28–78 individuals (Chapman, unpublished data)
    - ✔ Ten Thousand Islands/Everglades Area=284 individuals
    - ✔ Density estimates extrapolated to known area of breeding including areas in lower Florida Keys
  - ✔ Feldheim et al. (2017), determined that 55 females gave birth in the Charlotte Harbor Estuary and Smith et al. (2021) determined that 71 females gave birth in the Ten Thousand Islands/Everglades Unit
    - ✔ Density estimates extrapolated to known area of breeding including areas in lower Florida Keys

Updated Population Viability Model

Parameter	Value this study	Source	Previous value	Updated
Age-at-maturity	8 years	This study	7 and 11 years	Yes
Maximum age	30 years	Scharer et al. (2012)	30 years	No
Litter size (yr)	2.62 (0.504)	Brame et al. (2019) This study	3.1 (0.758)	Yes
Survivorship				
Age 0	0.87 (0.208)	Carlson and Simpfendorfer (2014)	0.87 (0.208)	No
Age 1	0.87 (0.131)		0.87 (0.131)	
Age 2	0.89 (0.104)		0.89 (0.104)	
Age 3	0.90 (0.093)		0.90 (0.093)	
Age 4	0.91 (0.087)		0.91 (0.087)	
Age 5-6	0.92 (0.082)		0.92 (0.082)	
Age 7-11	0.93 (0.080)		0.93 (0.080)	
Age 12-30	0.94 (0.080)		0.94 (0.080)	
Initial total population size	8075 females 2975 females 1255 females 1695 females	Ne/Nc: (Smith 2021) Ne/Nc ((Portnoy et al., 2009; Ahohen et al. 2009; Dudgeon and Ovenden, 2015). Breeders: (Feldheim et al. 2017); Smith et al. (2021) N_B: (Smith, 2021; Chapman, unpublished)	600 females 2250 females	Yes
Carrying capacity	45,000 females	Carlson and Simpfendorfer (2014)	45,000 females	No

- ✔ Estimates of fishing mortality by commercial shrimp trawlers were updated based on the information in the ESA Section 7 Consultation-Biological Opinion for the US Shrimp Fishery (NMFS, 2021).
  - ✔ 1806 smalltooth sawfish could be captured over any running 5 years, which equates to approximately 180 female and assuming 100%, 75%, 50%, and 25%
- ✔ No new information on shark bottom longline mortality
- ✔ New estimates of recreational fishing mortality using great hammerhead shark as a proxy (Cortes and Baertlein, 2021)

Scenario	Initial population size	Recreational Fishing Mortality	Shark Bottom Longline Mortalities	Shrimp Trawl Mortalities
1	8075	11	1	45
2	8075	11	1	90
3	8075	11	1	135
4	8075	11	1	180
5	2975	11	1	45
6	2975	11	1	90
7	2975	11	1	135
8	2975	11	1	180
9	1255	11	1	45
10	1255	11	1	90
11	1255	11	1	135
12	1255	11	1	180
13	1695	11	1	45
14	1695	11	1	90
15	1695	11	1	135
16	1695	11	1	180

Updated Population Viability Model

- ✔ An age-structured Leslie matrix model using data in the form of a pre-breeding census with inputs of fecundity and survivorship
- ✔ New estimates suggest smalltooth sawfish have moderate productivity based on Cortes (2016)
- ✔ Population was projected forward for 100 yr for each scenario. Stochasticity was incorporated by randomly drawing values specified in the Leslie matrix and replicating each time step 500 times

Leslie Matrix

$$L = \begin{bmatrix} F_0 & F_1 & F_2 & F_3 \\ S_0 & 0 & 0 & 0 \\ 0 & S_1 & 0 & 0 \\ 0 & 0 & S_2 & 0 \end{bmatrix}$$

Updated Population Viability Model Results

- ✔ The most dramatic declining trends resulted largely from the impact on the initial population size from the highest assumed fishing mortalities (100% and 75% post release mortality)
- ✔ Scenarios where the initial population was highest approached carrying capacity within 20 years when the level of fishing was lowest
- ✔ Scenarios where the population size was smallest were not able to successfully replace themselves despite the moderate level of productivity

Both studies suggest that key input variables for these optimistic scenarios is the initial population size and the true level of fishing mortality.

Challenges

- Still high level of uncertainty in estimates of genetic population size
  - (e.g. Ne=650 (95 % confidence limits 367–2358)
  - Reliable estimates are ultimately dependent upon the sampling regimes, number of loci (i.e., power of the data), and analytical approaches employed (Waples, 1989; Tallmon et al., 2004; Waples and Feutry, 2022).
- Main current sources of fishing mortality are from the southeast shrimp trawl fishery (Graham et al. 2022)
  - Estimates also subject to high levels of uncertainty
    - E.g. In 2009 in stat zone 2, estimated take was 96 (95 % confidence limits 0-351)
    - True rare event or low observer coverage

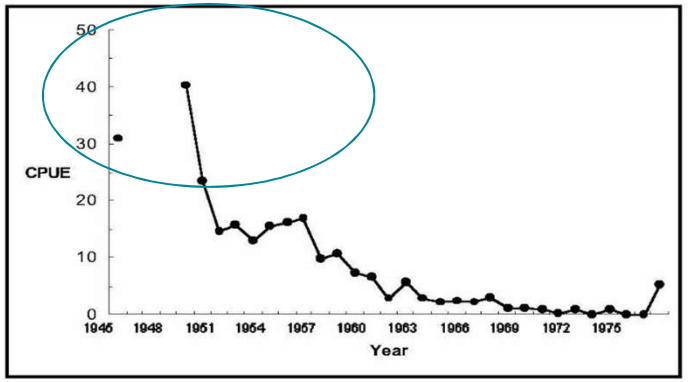


Figure 2. Mean annual landings of sawfish per trawler in Louisiana waters. Data from "Fisheries Statistics of the United States" (1945-1978, National Marine Fisheris Service). CPUE measured as landings per trawler.

Endangered Species UPDATE 47

Ways forward to advance PVA

- ✔ Refine bycatch estimates
  - ✔ Improve observer coverage and total effort for shrimp fishery
    - ✔ Potential for EM (Moncrief-Cox et al. 2020) and electronic logbooks
  - ✔ Opportunity for industry involvement

- ✔ Continue to improve life history, post release mortality data and population size information
  - ✔ Close-kin mark recapture study with Texas A&M University
    - ✔ Requires large sample size
    - ✔ Can industry assist in collecting samples
      - ✔ Tissue samples and tagging sawfish

QUESTIONS?