# STATUS REVIEW REPORT OF PACIFIC BLUEFIN TUNA

(*Thunnus orientalis*)

https://swfsc.noaa.gov/Pacificbluefintuna/


Prepared by the Pacific Bluefin Tuna Status Review Team

for the

Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service


May 15, 2017

**Acknowledgements**

The Pacific Bluefin Tuna Status Review Team would like to acknowledge the contributions of the following people who provided information that assisted in the development of this document: Campbell Davies (CSIRO), Mark Maunder (IATTC), John Walter (SEFSC), Kevin Piner (SWFSC), Owyn Snodgrass (NMFS), Gerard Dinardo (NMFS), Scott Rumsey (NMFS), and Heidi Taylor (NMFS).

This document should be cited as:

Pacific Bluefin Tuna Status Review Team. 2017. Status Review Report of Pacific Bluefin Tuna (*Thunnus orientalis*). Report to National Marine Fisheries Service, West Coast Islands Regional Office. May 15, 2017. 99pp.

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**EXECUTIVE SUMMARY**

On June 20, 2016 the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity (CBD) and 13 co-petitioners[1] requesting that Pacific Bluefin tuna, *Thunnus orientalis* (PBF), be listed as endangered or threatened under the Endangered Species Act (ESA) throughout all or a significant portion of its range. After review of the petition, NMFS published a positive 90-day finding in the *Federal Register* (81 FR 70074) on October 11, 2016, concluding that the petitioned actions may be warranted and announcing that a formal status review would be conducted as required by the ESA. A Status Review Team (SRT) was tasked to conduct this review.

Pacific bluefin tuna are a migratory pelagic species of fish primarily inhabiting the North Pacific Ocean and, to a lesser extent, in the Tasman Sea and around New Zealand. They are a top predator and have extraordinary swimming capabilities. Pacific bluefin are highly sought after for their flesh and both commercial and recreational fishing have contributed to a decline the population.

To conduct this Status Review, the SRT considered a variety of scientific information from the literature, unpublished documents, and direct communications with researchers working on PBF, as well as technical information submitted with the petition and by the petitioners and others in response to the 90-day finding. The SRT evaluated the risks presented by several threats to the degradation/decline of the PBF population. After considering the severity of these risks as ranked by the SRT, the SRT performed an overall extinction analysis. All risk/extinction analyses were performed considering two time frames: 25 years and 100 years into the future.

The SRT reviewed the current (2016) PBF stock assessment by the ISC. This assessment concluded that spawning stock biomass (SSB) fluctuated from 1952-2014, that SSB declined from 1996 to 2010, and the decline in SSB has ceased since 2010 yet remains near to its historic low. The stock assessment estimated that the number of spawning capable individuals is in excess of 140,000 and that the total population size is in excess of 1.6 million individuals. The current SSB is estimated to be 2.6 % of the theoretical, model derived SSB in the absence of fishing. The SRT noted that unfished SSB is a theoretical number derived from the stock assessment model and does not represent a "true" estimate of what the SSB would have been with no fishing. This is because it is based on the equilibrium assumptions of the model (e.g., no environmental or density-dependent effects) and it changes with model structures. That is, in the absence of density-dependent effects on the population, the estimate may overestimate the population size that can be supported by the environment and may change with improved input parameters. When compared to the highest estimated SSB in the model in 1959 of ~160,000 mt, the SSB in 2014 is 10.6 % of the 1952-2014 historical peak. Nevertheless, the SRT acknowledges that the current SSB is very low when compared to estimates of historical values.

[1] Prime Seafood, Ocean Foundation, Earthjustice, Center for Food Safety, Defenders of Wildlife, Greenpeace, Sylvia Earle Alliance/Mission Blue, Recirculating Farms Coalition, Safina Center, SandyHook SeaLife Foundation, Sierra Club, Turtle Island Restoration Network and WildEarth Guardians.

Among the 25 individual risks evaluated, the SRT concluded that overutilization, particularly by commercial fishing activities, has the greatest potential influence on population decline or degradation in PBF and poses a moderate risk to decline or degradation of the population over both the 25 and 100 year time scales. While the degree of certainty for this risk was moderate for the 25 year time frame, it was low for the 100 year time frame. This largely reflects the inability to accurately predict trends in both population size and catch over the longer time frame. In addition, management regimes may shift in either direction in response to the population trends at the time.

The SRT also concluded that inherent difficulties of international management posed a low risk to PBF over the short time frame, but a moderate risk to PBF over the long time frame. The SRT recognized the difficulty in managing a highly migratory species that spans multiple EEZs and that the challenges of this type of management have contributed to a decline in the PBF population. However, the management changes adopted in 2016 by the relevant RFMOs and participating countries have addressed the concern that PBF is being over utilized. The SRT also recognized that recommendations from IATTC and ISC to stakeholders for domestic regulatory and reporting measures have not only been adopted but also have been implemented. The increasing trend in the projected population across several management scenarios in the most recent stock assessment by the ISC, however, gave some confidence that the population was on a positive trajectory.

The SRT conducted an overall extinction risk analysis to summarize the risk of extinction to PBF. This risk analysis does not represent a decision by the SRT on whether the species should be or should not be listed under the ESA. The SRT utilized SEDM in assessing the severity of risk to extinction of PBF posed by all factors considered in the status report. Assessment of risk included a broad range of factors including the all ESA section 4(a)(1) categories, small population concerns, the results from the recent stock assessment, PBF life history parameters and strategy, and historic trends. After considering all factors herein, team members were asked to distribute 100 plausibility points across a range of severity for each of three risk categories as described below. This analysis was done over a short (25 year) and long (100 year) time scale.

The risk categories are as follows:

**Low risk**: A species or DPS is deemed to be at low risk of extinction if at least one of the following conditions is met: The species/DPS has high abundance or productivity; There are stable or increasing trends in abundance; The distributional characteristics of the species/DPS are such that they allow resiliency to catastrophes or environmental changes.

**Moderate risk**: A species or DPS is deemed to be at moderate risk of extinction if it is not at high risk and at least one of the following conditions is met: There are unstable or decreasing trends in abundance or productivity which are substantial relative to overall population size; There have been reductions in genetic diversity; The distributional characteristics of the species/DPS are such that they make the species vulnerable to catastrophes or environmental changes.

**High risk**: A species or DPS is deemed to be at high risk of extinction if at least one of the following conditions is met at levels that place the persistence of the species at risk: The abundance of the species/DPS is such that depensatory effects are plausible; There are declining trends in abundance that are substantial relative to overall population size; There is low and decreasing genetic diversity; There are current or predicted environmental changes that may strongly and negatively affect a life history stage for a significant period of time; The species/DPS has distributional characteristics that result in vulnerability to catastrophes or environmental changes.

The table below shows the SEDM results for the overall extinction risk for PBF on the short (25 year) and long (100 year) time scales with the highest score highlighted in grey. Numbers in the left column indicate team member. These numbers were randomly assigned to each team member and are not consistent among all tables in this report. The category with the highest mean number of assigned points is highlighted in grey.

| | Overall PBF Extinction Risk Threat SEDM (25 years) | | | Overall PBF Extinction Risk Threat SEDM (100 years) | | |
|---|---|---|---|---|---|---|
| | Low Risk | Moderate Risk | High Risk | Low Risk | Moderate Risk | High Risk |
| #1 | 90 | 10 | 0 | 80 | 20 | 0 |
| #2 | 60 | 40 | 0 | 55 | 45 | 0 |
| #3 | 50 | 50 | 0 | 10 | 35 | 55 |
| #4 | 80 | 10 | 10 | 70 | 20 | 10 |
| #5 | 100 | 0 | 0 | 75 | 25 | 0 |
| #6 | 80 | 20 | 0 | 60 | 35 | 5 |
| #7 | 15 | 70 | 15 | 10 | 75 | 15 |
| Mean | 67.86 | 28.57 | 3.57 | 51.43 | 36.43 | 12.14 |
| StDev | 28.85 | 25.45 | 6.27 | 29.54 | 19.30 | 19.76 |

Plausibility points were distributed across all three risk categories, however over the 25 year time frame, a large proportion were assigned to the low and moderate risk by some team members. Over the 100 year time frame, more points were assigned to the moderate and high risk categories. In both cases, the highest mean score was in the low risk category.

There are a number of factors that contributed to the low ranking of the overall extinction risk over both the 25 and 100 year time frames. The large number of mature individuals (>140,000), while small relative to the theoretical, model-derived unfished population, coupled with the overall population size (>1.6 million individuals), was deemed sufficient to allow PBF to avoid small population effects. In addition, the PBF population has experienced similarly low levels and has shown the ability to recover in the past, and is projected to increase in the current stock assessment. Harvest regulations have been adopted by member nations to reduce landings and rebuild the population. Also, the SRT noted that over the past 40 years the spawning stock biomass has experienced low levels relative to the theoretical, model-derived unfished population (less than 10% of unfished), and shown the ability to recover. While the SRT agreed that climate change has the potential to negatively impact the population, many members of the team felt that the PBF's broad distribution across habitat, vagile nature, and generalist foraging strategy were mitigating factors in terms of extinction risk.

While the SRT acknowledged the uncertainty associated with many factors such as the inability to forecast population numbers over long time scales, the inherent difficulties of international management, and the inability to predict adherence to enhanced regulatory measures, the majority of plausibility points in the final extinction risk analysis were distributed in the low risk category.

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*Note that tables embedded within the Executive Summary of the ISC 2016 stock assessment refer to the full ISC document and not this status report.

**LIST OF FIGURES***



*Note that figures embedded within the Executive Summary of the ISC 2016 stock assessment refer to the full ISC document and not this status report.

**LIST OF ACRONYMS AND ABBREVIATIONS USED IN THIS DOCUMENT**

| | |
|---|---|
| ADCP | Acoustic Doppler Current Profilers |
| CBD | Center for Biological Diversity |
| CCLME | California Current Large Marine Ecosystem |
| CDFW | California Department of Fish and Wildlife |
| CHL | chlordane |
| CMM | Conservation and management measure |
| CPFV | Commercial passenger fishing vessels |
| CPUE | Catch per unit effort |
| Cs | cesium radioisotopes |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DDT | Dichlorodiphenyltrichloroethane |
| DNA | deoxyribonucleic acid |
| DO | Disolved oxygen |
| DPS | Distinct population segment |
| EEZ | Exclusive Economic Zone |
| EPO | Eastern Pacific Ocean |
| ESA | Endangered Species Act |
| FDA | United States Food and Drug Administration |
| FL | Fork length |
| FLOSS | Fisheries mortality corresponding to the lowest observed spawning stock biomass |
| FMED | Median fisheries mortality reference point |
| FMP | Fisheries management plan |
| FR | Federal Register |
| FWS | United States Fish and Wildlife Service |
| GOM | Gulf of Mexico |
| Hg | mercury |
| HMS | Highly migratory species |
| IATTC | Inter-American Tropical Tuna Commission |
| ISC | International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean |
| IUU | Illegal, unregulated, and unreported |
| K | Potassium |
| M | mortality |
| MSA | Magnuson-Stevens Fishery Conservation and Management Act |
| NC | Census population size |
| NE | Effective population size |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NPO | North Pacific Ocean |
| NPTZ | North Pacific Transition Zone |
| OMZ | Oxygen Minimum Zone |
| PBDE | Polybrominated diphenyl ethers |
| PBF | Pacific Bluefin Tuna |

| | |
|---|---|
| PBFWG | Pacific Bluefin Tuna Working Group |
| PCB | polychlorinated biphenyl |
| PFMC | Pacific Fisheries Management Council |
| Po | Polonium |
| POP | Persistent organic pollutants |
| RCP | Representative Concentration Pathway |
| RFMO | Regional fisheries management organizations |
| SCB | Southern California Bight |
| SEDM | Structured Expert Decision Making process |
| SEFSC | Southeast Fisheries Science Center |
| SFA | Sustainable Fisheries Act |
| SPOIR | Significant portion of its range |
| SRT | Status Review Team |
| SS | Stock synthesis |
| SSB | Spawning stock biomass |
| SSBF=0 | theoretical unfished spawning stock biomass |
| SSBLOSS | Lowest observed spawning stock biomass |
| SSBMED | Median spawning stock biomass |
| SST | Sea surface temperature |
| StDev | Standard Deviation |
| SWFSC | Southwest Fisheries Science Center |
| TCA | Tuna Conventions Act |
| TZCF | Transition Zone Chlorophyll Front |
| WCPFC | Western and Central Pacific Fisheries Commission |
| WCPFCIA | Western and Central Pacific Fisheries Convention Implementation Act |
| WCPFC-NC | Western and Central Pacific Fisheries Commission Northern Committee |
| WCR | West Coast Region |
| WPO | Western Pacific Ocean |

# 1. INTRODUCTION AND BACKGROUND

## 1.1 Scope and intent of the status review

On June 20, 2016 the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity (CBD) and 13 co-petitioners[2] requesting that Pacific Bluefin tuna, *Thunnus orientalis* (PBF), be listed as endangered or threatened under the Endangered Species Act (ESA) throughout all or a significant portion of its range.

Under the ESA, a status review shall be promptly commenced if a petition is found to present substantial scientific or commercial information indicating that the petitioned action may be warranted (16 U.S.C. 1533(b)(3)(A)). After review of the petition, NMFS published a positive 90-day finding in the *Federal Register* (81 FR 70074) on October 11, 2016, concluding that the petitioned actions may be warranted and announcing that a formal status review would be conducted as required by the ESA. A Status Review Team (SRT) was tasked to conduct this review.

The purposes of this Status Review are to conduct a distinct population segment (DPS) analysis for PBF, identify and evaluate potentially significant threats to the species, and assess the species extinction risk. The status review analyzes the risk factors listed in section 4(a)(1) of the ESA: (A) the present or threatened habitat destruction or modification or curtailment of the species' habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; or (E) other natural or manmade factors affecting the species' continued existence.

To conduct this Status Review, the SRT considered a variety of scientific information from the literature, unpublished documents, and direct communications with researchers working on PBF, as well as technical information submitted with the petition and by the petitioners and others in response to the 90-day finding. The SRT relied heavily on the recently completed peer-reviewed stock assessment (ISC 2016). Information that were not previously peer-reviewed was formally reviewed by the SRT. The SRT evaluated all factors highlighted by the petitioners as well as additional factors that may contribute to PBF population vulnerability.

This document reports the results of the SRT's comprehensive status review of PBF. These conclusions are subject to revision should important new information arise in the future. This document is a compilation of the best available scientific and commercial information and a description of present and likely future threats to PBF. It does not represent a decision by the SRT on whether this population should be proposed for listing as threatened or endangered under the ESA. That decision will be made by NMFS after reviewing and considering the information and conclusions presented in this Status Review, efforts being made to protect the species, and all relevant laws, regulations, and policies. The decision will be posted on the NMFS Web site (http://www.nmfs.noaa.gov/pr/species/) and announced in the Federal Register.

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[2] Prime Seafood, Ocean Foundation, Earthjustice, Center for Food Safety, Defenders of Wildlife, Greenpeace, Sylvia Earle Alliance/Mission Blue, Recirculating Farms Coalition, Safina Center, SandyHook SeaLife Foundation, Sierra Club, Turtle Island Restoration Network and WildEarth Guardians.

## 1.2. Key factors in ESA evaluations

### 1.2.1. Qualification of a species under the ESA

For the purpose of the ESA, the term "species" includes (ESA section 3(16))

> "…any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature."

A distinct population segment, or DPS, must be "discrete" from other populations and "significant" to the taxon (species or subspecies) to which it belongs (see 61 FR 4722: February 7, 1996). A DPS is discrete if it is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological or behavioral factors. Alternatively, the DPS may be discrete if it is delimited by international governmental boundaries within which are notable differences in management of the species or its habitat. If a population segment is considered discrete, NMFS must then consider whether the discrete segment is "significant" to the taxon to which it belongs. Significance may be measured as persistence in a unique or unusual ecological setting, evidence that loss of the DPS would result in a significant gap in the range of the taxon, evidence that the discrete population segment represents the only surviving natural occurrence of a taxon within its historic range, or marked differentiation in its genetic characteristics. A population segment may include, but is not limited to, one of these criteria to be considered significant. This list of criteria is not exhaustive and other criteria relevant to the biology or ecology of the species may be used, as appropriate.

### 1.2.2. Determination of Extinction Risk

The ESA (Section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."

According to the ESA, determining whether a species is threatened or endangered through a consideration of the five risk factors mentioned above, should be made on the basis of the best scientific information available, after conducting a review of the status of the species, and taking into account efforts being made by any State or foreign nation, or any political subdivision of a State or foreign nation, to protect the species, whether by predator control, protection of habitat and food supply, or other conservation practices, within any area under its jurisdiction, or on the high seas.

## 1.3. Summary of information presented by the petitioners

The petition submitted by CBD and co-petitioners asserts that "[t]he [PBF] population's severe decline, in combination with inadequate regulatory mechanisms to end overfishing or reverse the decline, has pushed Pacific Bluefin tuna to the edge of extinction" and that listing of PBF as a threatened or endangered species under the ESA is needed to ensure that this population does not become extinct.

### 1.3.1. Species and DPS

The petitioners assert that PBF conforms to the definition of "species" under the ESA as stated above (section 1.2.1). The petitioners did not present any information asserting the presence of a DPS for PBF.

### 1.3.2. Risk factors

The petitioners assert that PBF qualifies as endangered or threatened under the ESA based on four of the five ESA section 4(a)(1) factors to be considered including: (1) Overutilization for commercial, recreational, scientific, or educational purposes; 2) inadequacy of existing regulatory mechanisms; 3) the present or threatened destruction, modification, or curtailment of the species' habitat or range; and 4) other natural or manmade factors that threaten the species' continued existence. The petitioners included information on the fifth factor of "disease or predation" within their discussion of the potential impacts of large scale aquaculture. We have included an analysis of these impacts. The petitioners presented the following information to support the proposed listing of PBF under the ESA.

#### 1.3.2.1 Overutilization for commercial, recreational, scientific, or educational purposes.

The petition states that fishing is the primary threat to PBF and is driving the species to extinction. The petitioners rely heavily on the stock assessment presented by the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) to reach their conclusions. This stock assessment indicates that the current (2014) spawning stock biomass of PBF is near 2.6% of its theoretical unfished[3] spawning stock biomass.

The petitioners assert that PBF life history makes them particularly vulnerable to overfishing. They indicate that PBF are targeted at every life stage from 15 cm long juveniles to spawning adults, and state that 97.6% of landed fish are taken before reaching spawning size. They also state that industrial fishing targets PBF during spawning periods on their two known spawning grounds. The petitioners raise concerns that the age of sexual maturity of PBF is a hindrance to recovery of the population. They also state that most of the large, and therefore more fecund, individuals have been removed from the population.

The petition states that overfishing, particularly in recent times, has resulted in a collapse of the PBF population and that historical overfishing has exacerbated this current threat. The petition describes the development of PBF fisheries in various regions of the North Pacific Ocean and documents declines in landings from their historic highs. The methods of take are described and temporal trends in landings are discussed. The petitioners also raise the concern that recreational landings in the U.S. have become a significant contribution to overall U.S. landings of PBF and that these individuals are juveniles that have not yet reproduced.

The petition also points to the impacts of aquaculture activities on the PBF population. The petitioners describe two types of aquaculture activities impacting PBF: Commercial grow-out

[3] Unfished refers to what spawning stock biomass would be had there been no fishing.

(“ranching”) and closed-cycle culture (brood stock used to spawn in captivity and individuals completing their life cycle in a closed facility). Concerns are raised that the number of small individuals harvested and placed in pens for grow-out impacts the overall PBF population and contributes to the population decline. The petition describes the rise in grow-out operations in Japan and Mexico from 1986 to the present and presents estimates of the number of fish taken to stock grow-out pens. Concerns are raised that once in pens, individuals are more susceptible to parasite infection and that the parasites may spread from penned fish to wild fish. The petition proposes that unregulated distribution or release of captive-spawned PBF eggs threaten PBF with genetic contamination. The largest concern raised by the petitioners is that aquaculture operations compete with wild PBF for prey. Given the high feed conversion ratio for PBF, large quantities of food items are required for growth and much of this may be derived from wild prey species.

#### 1.3.2.2 Inadequacy of existing regulatory mechanisms.

The petition describes the current state of PBF management on an international and domestic scale. The petitioners assert that the absence of science-based policies is a primary contributing risk factor for the extinction of PBF. The petition describes the regional fisheries management organizations responsible for PBF: The Inter-American Tropical Tuna Commission (IATTC) and the Western and Central Pacific Fisheries Commission (WCPFC). The lack of a large-scale rebuilding plan, the absence of agreed upon reference points, and lack of documentation on landings are highlighted as contributory factors to an inadequacy of management.

The petition describes the actions taken by the IATTC relating to PBF beginning in 2012. The petitioners assert that the IATTC failed to set appropriate catch limits based upon scientifically-based recommendations and that excess mortality due to discarded fish, recreational take, or post-release mortality was not built in to their plan. The petitioners predict that the current IATTC resolution (Resolution C-14-06 “Measures for the Conservation and Management of Pacific Bluefin Tuna in the Eastern Pacific Ocean, 2015-2016), which expired in 2016, would be the basis for the 2017/18 resolution without change. This was deemed to be a high-risk strategy given the current population trends and lack of efficacy of the 2015-2016 resolution.

The petition discusses the regulatory actions of the WCPFC from 2009 to the present. The petitioners assert that the target for the WCPFC PBF rebuilding plan reflected an already depressed population and was therefore inadequate to facilitate population increases to historical levels. Because the target value chosen was considered to be inappropriate, the petitioners assert that some countries were allowed to increase their catch under this plan and that it does not adequately limit fishing mortality. The petition also states that WCPFC did not take proper action in regard to its 2016 “emergency rule” that would be triggered when recruitment levels were detected to have dropped “drastically”.

The petition describes management actions within the U.S., which are stated to be replications of international rules. The petition states that annual catch limits set by NMFS for PBF are inadequate to reduce catch as they are set at levels higher than “normal” annual landings. The petitioners assert that the two domestic councils with jurisdiction over PBF stocks (Pacific Fishery Management Council [PFMC] and Western Pacific Regional Fishery Management

Council [WPFMC]) have failed to take appropriate actions to rebuild PBF stocks despite encouragement by NMFS.

The petition describes the U.S. recreational landings of PBF, their relative contribution to overall landings, and the management actions taken since 2007 for PBF. Recreational landings are presented and the petitioners state that from 2010-2013, recreational landings have been higher than commercial landings. The petitioners assert that the current management practice of setting daily bag limits is insufficient to limit the total catch of PBF by the recreational sector because there is no accompanying limit to absolute take by the fishery (i.e., the fishery is "open access" with no limits to the number of fishers who participate or number of trips each fisherperson can take). The bag limits set in 2007 (10 fish per angler) and 2015 (two fish per angler) were highlighted as inadequate because an analysis of historical catches showed that the vast majority of trips caught two or fewer PBF. The petition states that despite population declines of PBF described in the 2012 PBF stock assessment, total PBF landings in the U.S. increased in 2013 and 2014.

The petitioners highlight a drop in recreational landings since 2013 and attribute this to the closure of Mexican recreational fishing grounds in 2014 which are used by U.S.-based private and commercial passenger fishing vessels (CPFVs). The petition states that the U.S. has not adopted voluntary measures to reduce PBF landings such as those adopted by Mexico. The petition also states that the U.S. has failed to comply with IATTC regulations mandated in IATTC Resolution C-14-06 due to the following: "1) the use of bag limits in an open access fishery will not necessarily reduce recreational catch comparable with the commercial quota reduction, 2) neither the commercial nor recreational U.S. regulations implement the objective that only 50 percent of the total catch be comprised of fish less than 30 kilograms, and 3) the U.S. monitoring and reporting system is inadequate to abide by the weekly commercial catch reporting mandate, instead delaying reporting by up to 12 weeks and complicating quota management."

The petition states that despite a designation of "overfished" by NMFS in 2013, PBF management was inadequately altered by WPFMC and PFMC to affect reductions in landings in a sufficient time period.

#### 1.3.2.3 Present or threatened destruction, curtailment, or modification of species habitat or range.

The petition highlights chemical water pollution as a threat factor for PBF, particularly in relation to its lifespan and predatory nature, which facilitates bioaccumulation of pollutants. Mercury is stated to occur in bluefin tunas at levels exceeding those allowable by the U.S. Food and Drug Administration (USFDA) and that ocean acidification (a byproduct of climate change) may facilitate a more rapid uptake of mercury by PBF. The petitioners also highlight the presence of persistent organic pollutants (POPs) in Atlantic bluefin tuna and potential biological impairments caused by these chemicals. Additional pollutants highlighted as being problematic for PBF include DDT, particularly in the Southern California Bight, and radiation derived from the Fukushima power plant failure in Japan.

Additionally, the petition presents concerns about plastic pollution as a threatening factor for PBF. The petitioners assert that PBF may ingest plastic debris causing physical harm to the digestive tract, facilitating ingestion of POPs as these chemicals adhere to plastic debris, or physiological alteration of systems (e.g., reduced reproductive output). The petition highlights the growing problem of plastic pollution in the ocean as contributing to this threat.

The petition states that oil and gas development in the marine environment poses a threat to the continued existence of PBF. The petitioners assert that direct exposure to oil causes a suite of negative effects including "…behavioral alteration, suppressed growth, induced or inhibited enzyme systems and other molecular effects, physiological responses, reduced immunity to disease and parasites, histopathological lesions and other cellular effects, tainted flesh, and chronic mortality". The petition also states that the component compounds of petroleum oil (e.g., polycyclic aromatic hydrocarbons [PAHs]) are particularly toxic to early life stages of PBF.

The petition raises concerns that exposure to oil is primarily caused by acute and chronic spills, and secondarily by exploration activities. In the latter, negative impacts to water quality, ambient noise, and amount of debris in the ocean are highlighted. In particular, the petition raises concerns that seismic surveys used in oil and gas exploration are particularly harmful to PBF. The petitioners assert that the California coast and the Sea of Okhotsk (Russia) are areas of particular concern for PBF in relation to oil and gas exploration.

The petition states that offshore development of wind energy generators threatens to degrade PBF habitat by interfering with migration, feeding, or collisions/entanglement during construction and operation. The petitioners assert that the structures may attract or repel fish. The petition highlights a proposed wind energy development project off California as a particular concern.

The petition includes the development of offshore aquaculture projects as a threat to PBF habitat. The petitioners assert that these facilities would produce large amounts of waste products including excess feed, dead fish, and fish feces. The petition highlights a proposed facility off southern California as a particular concern.

The petition states that PBF habitat is also threatened by prey depletion as a direct result of competition by large-scale fisheries for prey species. The petitioners assert that secondary effects of climate change exacerbate this threat as they may alter patterns of prey and marine productivity. The petition highlights increasing fisheries for, and population declines in, squid, bottomfish, sardine, and anchovy as being of particular concern.

#### 1.3.2.4 Other natural or manmade factors that threaten the species' continued existence.

The petition states that climate change presents a threat to the continued existence of PBF. The petitioners list three primary factors resulting from climate change as specific threats: warming ocean temperatures, ocean acidification, and decreases in dissolved oxygen concentrations.

In relation to rising ocean surface temperatures, the petition states that PBF migration and spawning patterns will be negatively affected. Additionally, the petitioners raise concerns that larval survival will be negatively impacted by rising sea surface temperatures. The petition also raises concerns that large-scale ecosystem changes will negatively affect PBF, particularly in the California Current Large Marine Ecosystem (CCLME), due to rising sea surface temperatures. The petitioners highlight changes in PBF diet in recent years as an example. These changes are also stated to be associated with oceanographic alterations such as increased downwelling. The petitioners also assert that alterations in PBF feeding and migration will increase its vulnerability to fishing effort.

In relation to ocean acidification, the petition does not present specific threats to PBF, however it highlights potential effects on other fish species. Among those presented, the petition includes delayed hatching in yellowfin tuna eggs reared under varying pH levels, possible losses in senses (e.g., sight, smell, touch) in other fish species, and potential physiological changes such as acidosis and sub-lethal and lethal changes to circulatory mechanisms. The petitioners also assert that decreases in pH of the ocean will negatively affect fish's ability to regulate gas exchange across the gill surface.

In relation to dissolved oxygen (DO), the petition highlights changes in vertical habitat of fishes as a potential threat to PBF. In particular, the petitioners assert that the negative impact on PBF through this process will be due to "a decline of fish populations due to the constraints of the boundary layer and resulting increase in natural mortality". In addition, the petition states that oxygen limitations drive PBF migration in the eastern Pacific Ocean which will be altered by changes in DO and that the metabolic demand for oxygen created by large meals eaten in the eastern Pacific will not be met.

### 1.4 Time frames of Threat Evaluation and Extinction Risk Analysis

The SRT was tasked to provide an extinction risk analysis for PBF to facilitate NMFS' determination of its placement as either Endangered or Threatened. The ESA defines an endangered species as "any species which is in danger of extinction throughout all or a significant portion of its range" 16 U.S.C. § 1531(6). A threatened species is "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" 16 U.S.C. § 1531(20). The "foreseeable future" describes the extent to which the Secretary can, in making determinations about the future conservation status of the species, reasonably rely on predictions about the future (Department of the Interior Solicitor's Memorandum M-37021, "The Meaning of 'Foreseeable Future' in Section 3(20) of the Endangered Species Act"(Jan. 16, 2009)). The SRT was not asked to determine the placement of PBF into either the Endangered or Threatened category and the conclusions in this report do not represent NMFS' decision regarding the listing of PBF under the ESA.

The SRT discussed the extinction risk analysis and what factors should be considered. It was agreed that it would be necessary to rely on predictions of future trends in factors across the ESA section 4(a)(1) threat categories when information was available. These predictions included extrapolation of population or threat trends, analysis of how threats may affect the status of the species, and assessment of future events that may have a significant impact on the species. The

SRT also considered the life history of the PBF, its habitat characteristics, the availability of data, the kinds of threats, the ability to predict threats and their impacts, and the reliability of models used to forecast these threats over time in determining the time period over which the extinction risk analysis was to be conducted.

Given the considerations above, the SRT agreed that it was necessary to evaluate extinction risk over two time frames, 25 years (~3 generations) and 100 years (~13 generations). The SRT concluded that the short time frame was a realistic window to evaluate current effects of potential threats with a good degree of reliability, especially when considering the limits of population forecasting models (e.g., projected population trends in stock assessment models). However, the SRT was also concerned that certain threats could not be adequately evaluated over a 25 year time period. The SRT also concluded that 100 years was a more realistic window through which to evaluate the effects of a threat in the more distant future that, by nature, may not be able to be evaluated over shorter time periods. For example, the potential effects of climate change from external forcing are best considered on multi-decadal to centennial timescales, due to the predominance of natural variability in determining environmental conditions in the shorter term. In addition, extinction risk analyses over a short and long time frame have been used in previous status reviews of marine species (e.g., Great White Shark, Ringed Seal) and 100 years into the future has been used as a long-term benchmark. The SRT therefore concluded that two extinction risk analyses would be performed, one over a 25 year period, and one over a 100 year time period.

### 1.5. Overview of the status review process

The SRT performed the status review in accordance with NMFS Office of Protected Resources guidelines. The primary step was to compile the best available information from all potential sources. After initial review of this information, the SRT determined if the identification of any Distinct Population Segments (DPSs) was appropriate. Following the determination of the existence of any DPSs, the SRT reviewed the stock assessment, examined and characterized potential threats to the population, and ultimately conducted a risk assessment to assess the level of extinction risk for PBF throughout all or a significant portion of its range. Finally, the status review report was prepared and submitted to the appropriate regional office.

The review process was somewhat hierarchical in nature. First, individual threats were evaluated in terms of their effects on PBF population decline and/or degradation (these being intrinsically linked to extinction risk). Second, the cumulative effects on population decline and/or degradation of all individual threats in each ESA section 4(a)(1) category was assessed. Finally, these cumulative risks to population decline/degradation were evaluated and an overall extinction risk assessment was performed.

## 2. BACKGROUND INFORMATION ON PACIFIC BLUEFIN TUNA

### 2.1 Taxonomy and Description of Species

Pacific Bluefin tuna (*Thunnus orientalis*) belong to the family Scombridae (order Perciformes). They are one of three species of Bluefin tuna which also include the Southern Bluefin Tuna

(*Thunnus maccoyii*) and the Atlantic Bluefin Tuna (*Thunnus thynnus*). The three species can be distinguished based on internal and external morphology as described by Collette (1999). The three species are also distinct genetically (Chow and Inoue, 1993; Chow and Kishino, 1995) and have some overlap in their geographic ranges.

Pacific Bluefin Tuna are large predators reaching nearly three meters in length and 500 kg in weight (ISC, 2016). They are pelagic species known to form large schools. As with all tunas and mackerels, PBF are fusiform in shape and possess numerous adaptations to facilitate efficient swimming. These include depressions in the body which accommodate the retraction of fins to reduce drag and a lunate tail which is among the most efficient tail shapes for generating thrust in sustained swimming (Bernal et al., 2001).

One of the most unique aspects of PBF biology is their ability to maintain a body temperature that is above ambient (endothermy). While some other tunas and billfishes are also endothermic, these adaptations are highly advanced in the bluefin tunas (Carey et al., 1971; Graham and Dickson, 2001) that can elevate the temperature of their viscera, locomotor muscle and cranial region. The elevation of their body temperature enables higher metabolic performance and allows for the exploitation of a broader habitat range vertically and geographically than would be available otherwise (Bernal, et al., 2001).

### 2.2 Range, habitat use, and migration

Pacific Bluefin Tuna are a highly migratory species that are primarily distributed in sub-tropical and temperate latitudes of the North Pacific Ocean (NPO) between 20°N and 50°N. They are also found in tropical waters and in the southern hemisphere around New Zealand and in the Tasman Sea (C. Davies, pers. comm.; Bayliff, 1994; Figure 1)

As a pelagic species, PBF utilize a range of habitats including open-water, coastal seas, and seamounts. PBF occur from the surface to depths of at least 550 m although they spend most of their time in the upper 120 m of the water column (Kitagawa, et al., 2000; 2004; 2007; Boustany et al. 2010). As with many other pelagic species, PBF are often found along frontal zones where forage tends to be concentrated (Kitagawa, et al., 2009). Off the west coast of the U.S., PBF are often more tightly clustered near areas of high productivity and more dispersed in areas of low productivity (Boustany, et al., 2010).

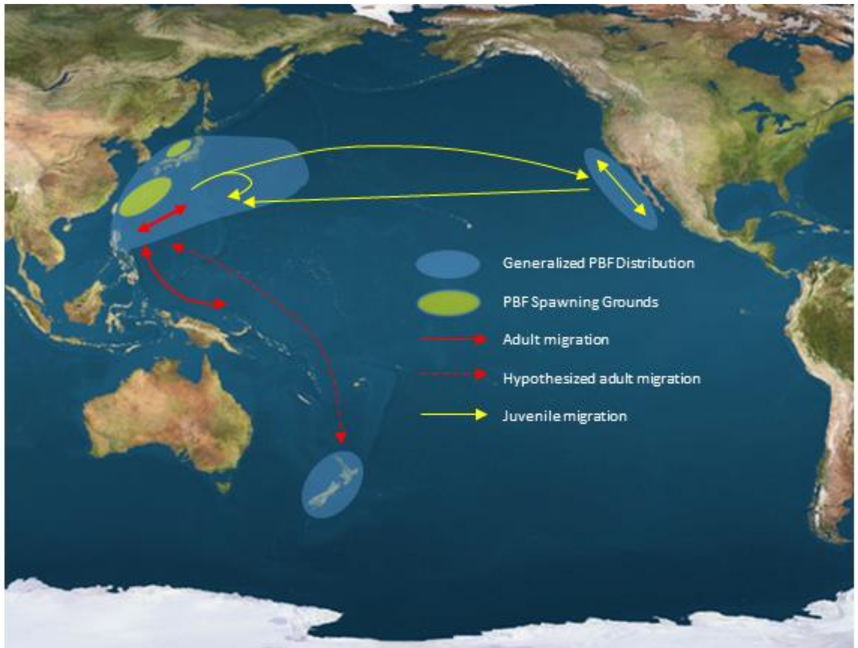



**Figure 1. Generalized PBF distribution, migration pathways, and spawning grounds. Note that PBF occur throughout their migratory pathways and highlighted areas are generalized around fishing areas.**

Pacific Bluefin Tuna exhibit large inter-annual variations in movement (e.g., numbers of migrants, timing of migration and migration routes), however general patterns of migration have been established using catch data and through tagging studies (Bayliff 1994; Boustany et al. 2010; Block et al. 2011; Whitlock et al. 2015). PBF begin their lives in the western Pacific Ocean (WPO). Generally, age 0-1 fish migrate north along the Japanese and Korean coasts in the summer and south in the winter (Inagake et al. 2001, Itoh et al. 2003). Depending on ocean conditions, an unknown portion of young individuals (1-3 years old) from the WPO migrate eastward across the NPO, spending several years as juveniles in the eastern Pacific Ocean (EPO) before returning to the WPO (Bayliff, 1994, Inagake et al. 2001, Perle 2011). These migration rates have not been quantified and it is unknown what proportion of the population migrates to the EPO and what factors contribute to the high degree of variability across years.

While in the EPO, the juveniles make north-south migrations along the west coast of North America (Kitagawa et al. 2007, Boustany et al. 2010, Perle, 2011). PBF tagged in the California Current are primarily located between Monterey Bay (36°N) and Baja California (23°N) (Boustany et al. 2010; Block et al. 2011; Whitlock et al. 2015), although some individuals have been recorded as far north as Washington. This migration loosely follows the seasonal cycle of surface temperature, such that PBF move northward as temperatures warm in late summer to fall (Block et al. 2011). These movements also follow shifts in local peaks in primary productivity (as measured by surface chlorophyll) (Boustany et al. 2010; Block et al. 2011). In the spring, PBF are concentrated off the southern coast of Baja California, in summer, PBF move northwest into the Southern California Bight, by fall, they are largely distributed between northern Baja California and northern California. In winter, PBF are generally more dispersed, with some individuals remaining near the coast, and some moving farther offshore (Boustany et al. 2010).

For the portion of the population that has migrated to the EPO, after spending up to 5 years in the EPO, individuals return to the WPO where the only two spawning grounds have been documented (see below). No spawning activity, eggs, or larvae have been observed in the EPO. Following their return to the WPO, spawning behavior and/or location has not been established. Mature adults in the WPO generally migrate northwards to feeding grounds after spawning (see section 2.3 for a discussion of spawning grounds), although a small proportion of fish may move southward or eastward (Itoh 2006). Some mature individuals also migrate as far as the South Pacific and are taken in New Zealand fisheries (Bayliff 1994, Smith, et al., 2001), however the migration pathway of these individuals is unknown. It is also not known how long they may remain in the South Pacific.

### 2.3 Reproduction and growth

Like most pelagic fish, PBF are broadcast spawners and spawn more than once in their lifetime and repeatedly within a given spawning season (Okochi, et al., 2016). Spawning occurs daily (Okochi, et al., 2016), and PBF are highly fecund. Batch fecundity is positively and linearly correlated with fish length and weight (Okochi, et al., 2016; Ashida, et al., 2015). Estimates of batch fecundity for females from the southern spawning area (Taiwan) indicate that fish ~195 cm can produce at least five million eggs per batch, while fish ~230 cm can produce at least 25 million eggs per batch (Shimose et al., 2016; Chen et al, 2006). Ashida et al. (2015) report a maximum single spawning batch at >35 million eggs in an individual ~220 cm. Females in the northern spawning ground (Sea of Japan) produce 780,000 – 13.89 million eggs per batch in fish 116-170 cm FL (Okochi, et al, 2016). Spawning in females occurs nearly every day during the spawning season (Okochi, et al., 2016).

Histological studies have shown that 80% of individuals ~115 cm FL and ~30 kg (age 3) in the Sea of Japan from June to August are reproductively mature (Tanaka, et al., 2006, Okochi et al. 2016). This percent maturity, however, does not necessarily represent the whole population as fish outside the Sea of Japan (not on spawning grounds) were not examined. This is reflected in the ISC stock assessment which assumes 20% maturity at 3 years of age

Spawning in PBF only occurs in comparatively warm waters, so larvae are found within a relatively narrow sea surface temperature (SST) range (~23.5 – 29.5°C) compared to juveniles and adults (Kimura et al. 2010; Tanaka & Suzuki 2016).

Spawning in PBF is localized in areas with a specific combination of oceanographic features and has only been recorded in two locations: near the Philippines and Ryukyu Islands, and in the Sea of Japan (Figure 1) (Okochi et al. 2016; Shimose & Farley 2016). These two spawning grounds differ in both timing and the size composition of individuals. Near the Ryukyu Islands, spawning occurs from April to July and fish are from 6-25 years of age although most are older than 9 years of age. In the Sea of Japan, spawning occurs later (June to August) and fish are 3-26 old. Larvae from the southern spawning ground are thought to be transported primarily by the northward flowing Kuroshio Current. Nursery areas are located off of coastal Japan, both in the Pacific and Sea of Japan (Kimura et al., 2010).

Pacific Bluefin Tuna exhibit rapid growth, reaching >58 cm in the first year of life and >1m by age three (Shimose et al., 2009; Shimose and Ishihara, 2015). Growth rate slows with age, reaching a plateau around age 15 at ~230 cm (Shimose et al., 2009; Shimose and Ishihara, 2015). The oldest PBF recorded was 26 years old and 246 cm (Shimose et al., 2009), however the maxium age may be larger but unrecorded.

### 2.4 Feeding habits

Pacific Bluefin tuna are opportunistic feeders. Small individuals (age 0) feed on small squid and zooplankton (Shimose et al. 2013). Larger individuals (age 1+) have a diverse forage base that is temporally variable and in both the EPO and WPO, they feed on a variety of fishes, cephalopods, and crustaceans (Pinkas et al., 1971; Shimose et al., 2013; Madigan et al., 2016; O. Snodgrass, NMFS SWFSC 2017 unpublished data). Diet data indicate they forage in surface waters, on mesopelagic prey and even on benthic prey. Figure 2 depicts stomach content analysis of age 1-5 PBF caught off the coast of California from 2008-2016 (O. Snodgrass, SWFSC, unpublished data). These data demonstrate that PBF are generalists and alter their feeding habits depending on localized prey abundance.

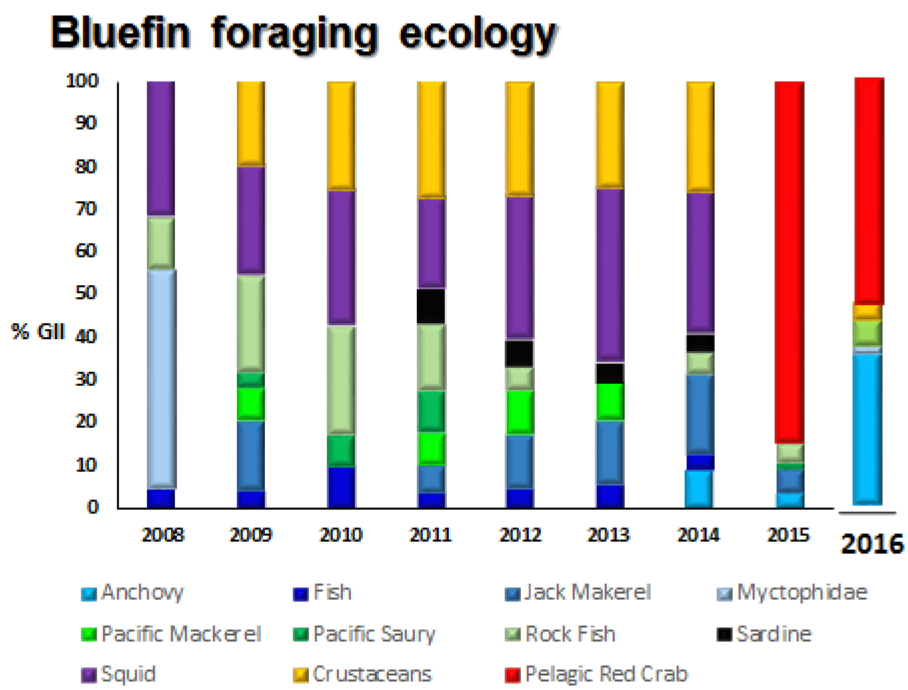



**Figure 2. Prey items found within the stomachs of PBF in the EPO 2008-2016 (O. Snodgrass, SWFSC, unpublished data) showing the diverse and temporally variable diet of PBF.**

# 3. CONSIDERATION OF A DISTINCT POPULATION SEGMENT UNDER THE ESA

## 3.1. ESA discreteness and significance criteria

Joint National Oceanic and Atmospheric Administration (NOAA)/ U.S. Fish and Wildlife Service (FWS) policy defines a population to be a distinct population segment (DPS) if it is both discrete and significant relative to the taxon to which it belongs (61 *FR* 4722, February 7, 1996). Under the policy, a population may be considered discrete if it satisfies one of the following conditions:

- It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
- It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of Section 4(a)(1)(D) of the ESA.

If a population segment is considered discrete, NMFS must then consider whether the discrete segment is significant to the taxon to which it belongs. In carrying out this examination, NMFS will consider available scientific evidence for this significance. This consideration may include, but is not limited to:

- persistence of the discrete segment in an ecological setting unusual or unique for the taxon,
- evidence that loss of the discrete segment would result in a significant gap in the range of the taxon,
- evidence that the discrete segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or
- evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

Because precise circumstances are likely to vary from case to case, it is not possible to describe prospectively all the classes of information that might bear on the biological and ecological importance of a discrete population segment. Thus, in addition to the four criteria listed above, the policy also allows for consideration of other factors, if they are appropriate, based on the biology or ecology of the species.

## 3.2 SRT consideration of ESA discreteness

Pacific Bluefin tuna are currently managed as a single stock with a trans-Pacific range. The SRT considered a number of factors related to PBF movement patterns, geographic range and life history that relate to the discreteness criteria. Among the many characteristics of PBF that were discussed as contributing factors to the determination of ESA discreteness, three were regarded as being the most important: the spatial specificity of PBF spawning, PBF migratory behavior, and genetics.

Based on the current understanding of PBF movements (see section 2.2 for description of movements), PBF utilize one of two areas in the WPO to spawn. There is no evidence to suggest that these represent two separate populations but instead that as fish increase in size they shift from using the Sea of Japan to the spawning ground near the Ryukyu Islands (e.g., Shimose et al., 2016). The spawning areas are also characterized by a combination of oceanographic conditions, rather than a spatially fixed feature (e.g., a seamount or promontory). This implies that the location of the spawning grounds may be temporally and spatially fluid, as conditions change over time. Given these considerations, the existence of spatially distinct spawning grounds does not provide compelling evidence that a discrete population segment exists for PBF. In addition, concentrations of adult PBF on the spawning grounds is only during spawning times and not year round.

Catch data and conventional and electronic tagging data demonstrate the highly migratory nature of PBF. Results support broad mixing around the Pacific. While PBF make trans-Pacific migrations, results indicate that they then return to the WPO to spawn. While additional information on fish in the South Pacific is needed, there is no evidence to support discrete population segments (see section 2.2 for description of migratory behavior). In addition, the limited genetic data currently available (Tseng et al., 2012; Nomura et al., 2014) do not support the presence of genetically distinct partitions within the PBF population.

### 3.3 SRT DPS determination

The SRT considered the best available biological and ecological information in addressing this topic. The definition for Distinct Populations Segments requires evidence that the putative DPS is both distinct and significant. There is no data to support that there is a segment of the PBF population that is discrete. The SRT was unanimous in its determination that no DPS should be designated for PBF. Given that no DPS was identified within the range of PBF, the “significance” criteria for a DPS were not considered.

## 4. CONSIDERATION OF SIGNIFICANT PORTION OF SPECIES RANGE

### 4.1 ESA significant portion of a species range (SPOIR) criteria

In addition to deciding whether PBF met the DPS criteria, the SRT was asked to identify whether there are any specific portions of the species' geographic range that are significant in terms of the population’s overall viability, and which if lost would significantly increase the population’s risk of extinction. This approach was taken to be consistent with the NMFS-FWS policy on interpreting the phrase “significant portion of a species range” in the ESA definitions of threatened and endangered species (79 FR 37578; July 1 2014). Under this policy, a portion of the range of a species is “significant” if its contribution to the viability of the species is so important that, without that portion, the species would be in danger of extinction.

### 4.2 SRT consideration of SPOIR of PBF range

To date, no marine species has been determined to meet the criteria for SPOIR. The use of SPOIR has typically been for terrestrial species and relates to a portion of the range where the organism spends its full life-cycle; it has yet to be used to classify a specific life stage. Because PBF range broadly throughout their lifecycle around the Pacific basin, there was no portion of the range that, if lost, would increase the population's extinction risk. In other words, risk of specific threats to PBF are buffered both in space and time.

To be thorough, the SRT examined the potential for a SPOIR by considering the greatest known threats to the species and whether these were localized to a significant portion of the range of the whole DPS. The main threats to PBF populations identified by the SRT were overutilization, inadequacy of management, and climate change. These threats are spread throughout the range of PBF and not localized to a specific region.

### 4.3 SRT determination of SPOIR

The SRT considered the best available information in addressing this topic. The definition for SPOIR requires the identification of significant portion of the range which if lost would significantly increase the population's risk of extinction.  The SRT was unanimous in its determination that no SPOIR should be designated for PBF.

## 5. PACIFIC BLUEFIN STOCK ASSESSMENT

The Pacific bluefin tuna (PBF) fishery is managed under the authorities of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), the Tuna Conventions Act of 1950 (TCA), and the Western and Central Pacific Fisheries Convention Implementation Act (WCPFCIA). The TCA and WCPFCIA authorize the Secretary of Commerce to implement the conservation and management measures of the Inter-American Tropical Tuna Commission (IATTC) and Western and Central Pacific Fisheries Commission (WCPFC), respectively. Both of these regional fisheries management organizations (RFMOs) receive scientific information on PBF, such as stock status, from the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). The ISC is a primary source for PBF stock assessments, the most recent of which was published in 2016. In addition, the IATTC also conducts its own stock analysis based on PBF data in conjunction to provide management advice.

### 5.1 PBF ISC Stock Assessment

The ISC stock assessment presented population dynamics of PBF based on catch per unit effort (CPUE) data from 1952-2015 using a fully integrated age-structured model (Stock Synthesis v. 3.24f).  The model included various life-history parameters including a length/age relationship and natural mortality estimates from tag-recapture and empirical life-history studies. Specific details on the modelling methods can be found in the ISC stock assessment available at http://isc.fra.go.jp/reports/stock_assessments.html.

The SRT acknowledges that every stock assessment has assumptions, either implicit or explicit, regarding biological processes, sampling errors and model structure. This is nearly always due to a lack of reliable data on these processes, particularly when it comes to basic life history and population structure. This situation is particularly apparent in PBF as many key biological factors are unknown as outlined in this report. The SRT considered that the assumptions in the ISC stock assessment model were based on the best available information for model input parameters and estimations. The SRT also acknowledges that the abundance indices used as input data for the model are reliant upon fisheries dependent data as there are no reliable abundance indices available from fisheries independent data. As with any dataset, fisheries dependent data has both strengths and weaknesses, however in the absence of fisheries independent data, they are the best available data with which to work. While the SRT was not tasked to review the merits of the 2016 ISC stock assessment, it did consider it to be the best available science and therefore it was considered in full.

The 2016 ISC PBF stock assessment indicated three major trends:

1. Spawning stock biomass (SSB) fluctuated from 1952-2014,
2. SSB declined from 1996 to 2010, and
3. The decline in SSB has ceased since 2010 yet remains near to its historic low.

Based on the stock assessment model, the 2014 SSB was estimated to be ~17,000 mt which represents 143,053 individuals capable of spawning. Relative to the theoretical, model-derived SSB had there been no fishing (i.e., the “unfished” SSB; 644,466 mt, s.d. 13,603 mt), 17,000 mt represents ~2.6 % of fish in the spawning year classes. It is important to note that unfished SSB is a theoretical number derived from the stock assessment model and does not represent a “true” estimate of what the SSB would have been with no fishing. This is because it is based on the equilibrium assumptions of the model (e.g., no environmental or density-dependent effects) and it changes with model structures. That is, in the absence of density-dependent effects on the population, the estimate may overestimate the population size that can be supported by the environment and may change with improved input parameters. When compared to the highest estimated SSB in the model in 1959 of ~160,004 mt, the SSB in 2014 is 10.6 % of the 1952-2014 historical peak.

As with most marine fish species, the number of individuals in younger age classes are expected to be higher than those in older age classes due to natural mortality. In many cases there is a natural, dramatic decrease in the number of individuals across younger age classes. Figure 3 shows the predicted number of individuals in age classes 0-8 for the 2014 PBF population based on the ISC 2016 stock assessment based on natural mortality (M) alone.

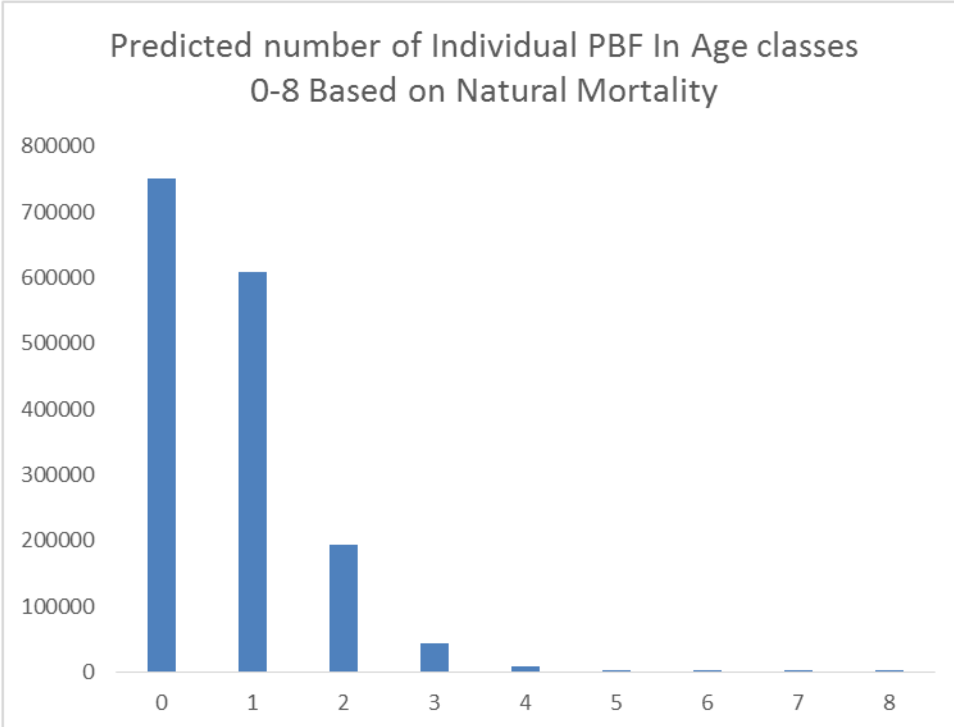



**Figure 3. Predicted number of individual PBF in each age class from 0-8 years due to natural mortality (M) showing the normal decline in number of individuals as age class increases. Values assume 2014 age 0 estimated population size and natural mortality schedule used in the 2016 ISC stock assessment.**

As expected, there is a sharp decline in the number of individuals from the younger age classes to the older age classes. It is important to note that while the spawning stock biomass as estimated by the ISC stock assessment is 2.6 %, this value is based on a theoretical unfished population, and only includes fish of spawning size/age. Based on the estimated number of individuals at each age class, the number of spawning capable individuals in 2014 was 143,053. However, total population size including non-spawning capable individuals is estimated at 1,625,837. This yields an 8 % ratio of spawning capable individuals to total population. From 1952-2014, this ratio has ranged from 28 % in 1960 to 2.5 % in 1984, with a mean of 8%. The ratio in 2014 indicates that, relative to population size, there were more spawning capable fish than in other years even with similarly low total population size (e.g., 1982-84) and was at the average for the period 1952-2014 (Figure 4). While this ratio may be influenced by a lower number of recruits in 2014, it may be an indication that the SSB is sufficient to facilitate a similar recovery to that seen after 1984.

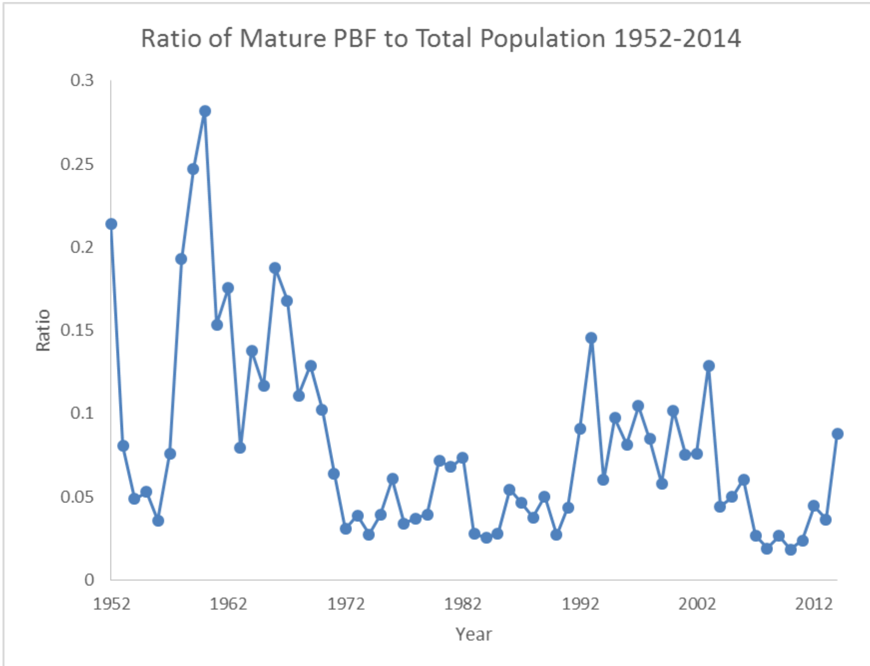



**Figure 4. Ratio of the number of mature individuals to total number of individuals in the PBF population based on the 2016 ISC stock assessment 1952-2014.**

The 2016 ISC stock assessment was also used to project changes in SSB through the year 2034. The assessment evaluated 11 scenarios in which various management strategies were altered from the status quo (e.g., reduction in landings of smaller vs. larger individuals) combined with variable recruitment scenarios (e.g., low to high recruitment). None of these 11 scenarios resulted in a projected reduction in SSB through fishing year 2034.

The stock assessment also presents Kobe plots indicating that PBF is overfished and that overfishing is occurring. These plots, however, are based on the 2014 regulations and do not take into account new regulatory measures that have been implemented. These new regulatory measures may cause overfishing to cease, however these analyses have yet to be conducted.

To ensure accurate representation and to include sufficient information, the executive summary of the ISC stock assessment is presented below. The full document including references may be found at http://isc.fra.go.jp/reports/stock_assessments.html.

Note: Figure numbers and legends in the following section refer to those in the ISC stock assessment document.

**2016 Pacific Bluefin Tuna Stock Assessment ISC PBFWG**

**EXECUTIVE SUMMARY**

## 1. Stock Identification and Distribution

Pacific bluefin tuna (*Thunnus orientalis*) has a single Pacific-wide stock managed by both the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). Although found throughout the North Pacific Ocean, spawning grounds are recognized only in the western North Pacific Ocean (WPO). A portion of each cohort makes trans-Pacific migrations from the WPO to the eastern North Pacific Ocean (EPO), spending up to several years of its juvenile life stage in the EPO before returning to the WPO.

## 2. Catch History

While Pacific bluefin tuna (PBF) catch records prior to 1952 are scant, there are some PBF landings records dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Catch of PBF was estimated to be high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935; thereafter catches of PBF dropped precipitously due to World War II. PBF catches increased significantly in 1949 as Japanese fishing activities expanded across the North Pacific Ocean. By 1952, a more consistent catch reporting process was adopted by most fishing nations. Estimates indicate that annual catches of PBF fluctuated widely from 1952-2014 (Figure 1). During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. While a suite of fishing gears have been used to catch PBF, the majority is currently caught in purse seine fisheries (Figure 2). Catches during 1952-2014 were predominately composed of juvenile PBF, but since the early 1990s, the catch of age 0 PBF has increased significantly (Figure 3).

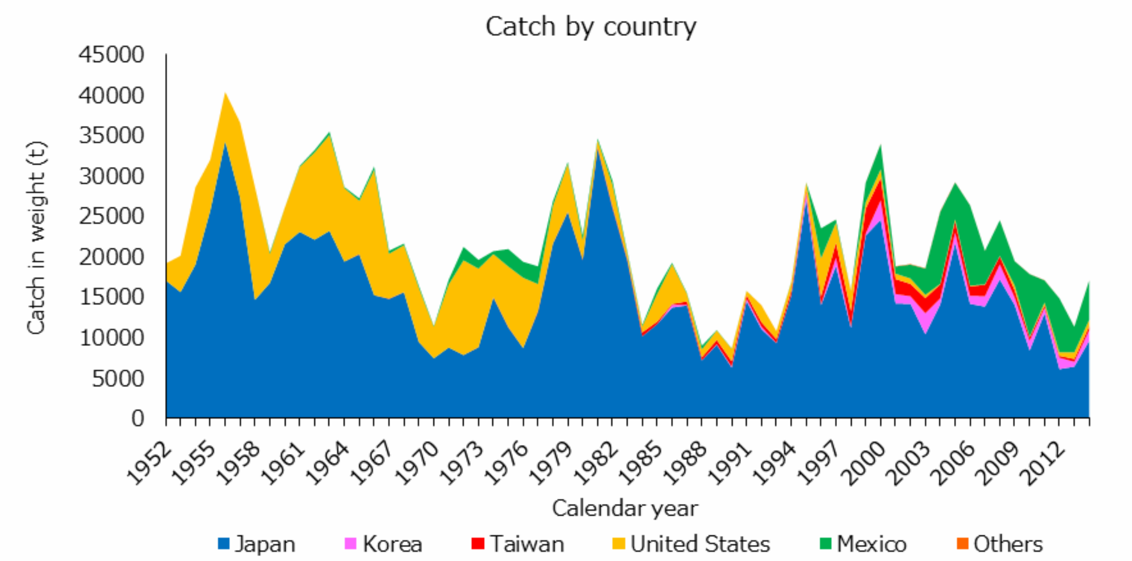



**Figure 1.** Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by country from 1952 through 2014 (calendar year).

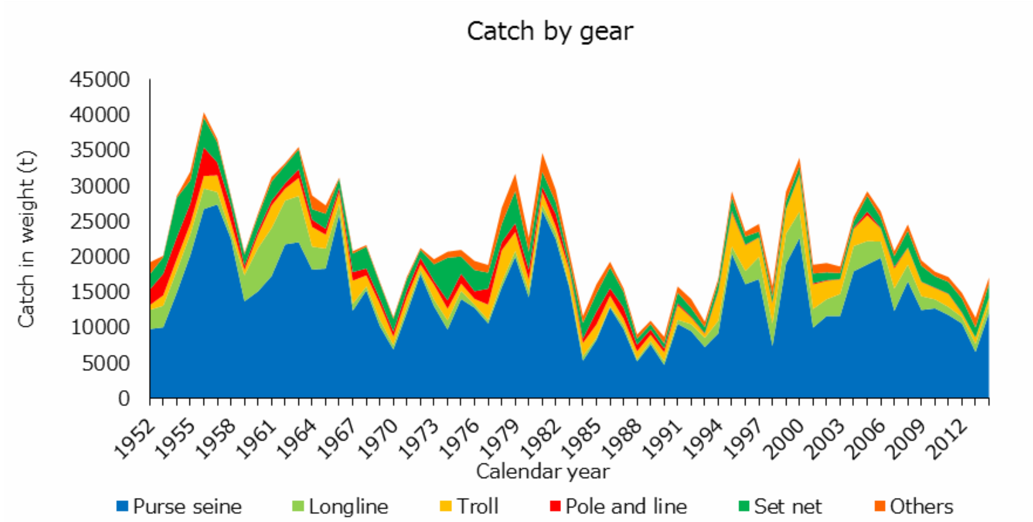



**Figure 2.** Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2014 (calendar year).

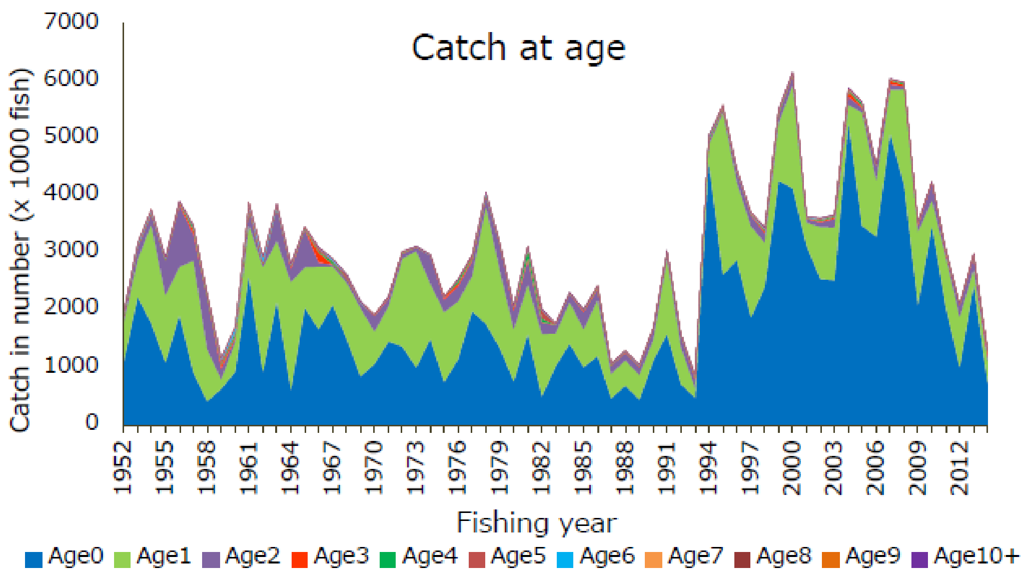



Figure 3. Annual catch-at-age of Pacific Bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2014).

**3. Data and assessment**

Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis (SS) v3.24f) fitted to catch, size-composition and catch-per-unit of effort (CPUE) data from 1952 to 2015, provided by Members of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), Pacific Bluefin Tuna Working Group (PBFWG) and non-ISC countries. Life history parameters included a length-at-age relationship from otolith-derived ages, and natural mortality estimates from a tag-recapture study and empirical-life history methods.

A total of 19 Fleets were defined for use in the stock assessment model based on country/gear/season/region stratification. Quarterly observations of catch and size compositions, when available, were used as inputs to the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water, off-shore and coastal longline, the Taiwanese longline and the Japanese troll fleets were used as measures of the relative abundance of the population. The assessment model was fitted to the input data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived outputs and their variances were used to characterize stock status and to develop stock projections.

In the previous assessments, it was found that conflicts existed among data in the model. However, stock biomass trends were consistent among tested model runs and conservation advice based on those results was provided. The 2016 assessment model was developed and refined in the intervening three years based on improvements made by PBFWG scientists. The improvements include: more accurate historical catch data, a better estimate of size composition by fleet, improved standardization of abundance indices, a revised growth curve based on additional otolith formation and standardization of aging techniques, and improved model settings to represent the best input data.

## 4. Stock Status and Conservation Advice accepted as ISC16 Plenary

### Stock Status

The PBFWG conducted a benchmark assessment (base-case model) using the best available fisheries and biological information. For data considered reliable, the base-case model fits the data well and is internally consistent among most of the other sources of data. The model is a substantially improved from the 2014 assessment. The base-case model indicates: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (fishing years 1952-2014) and (2) the SSB steadily declined from 1996 to 2010; and (3) the decline appears to have ceased since 2010, although the stock remains near the historic low. The model diagnostics suggest that the estimated biomass trend for the last 30 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations.

Using the base-case model in the 2016 assessment, the 2014 (terminal year) SSB was estimated to be around 17,000 t (Figure 7-4), which is about 9,000 t below the terminal year estimated in the 2014 assessment (26,000 in 2012). This is because of improvements to the input data and refinements to the assessment model which scaled down the estimated value of SSB, and not because the SSB declined from 2012 to 2014.

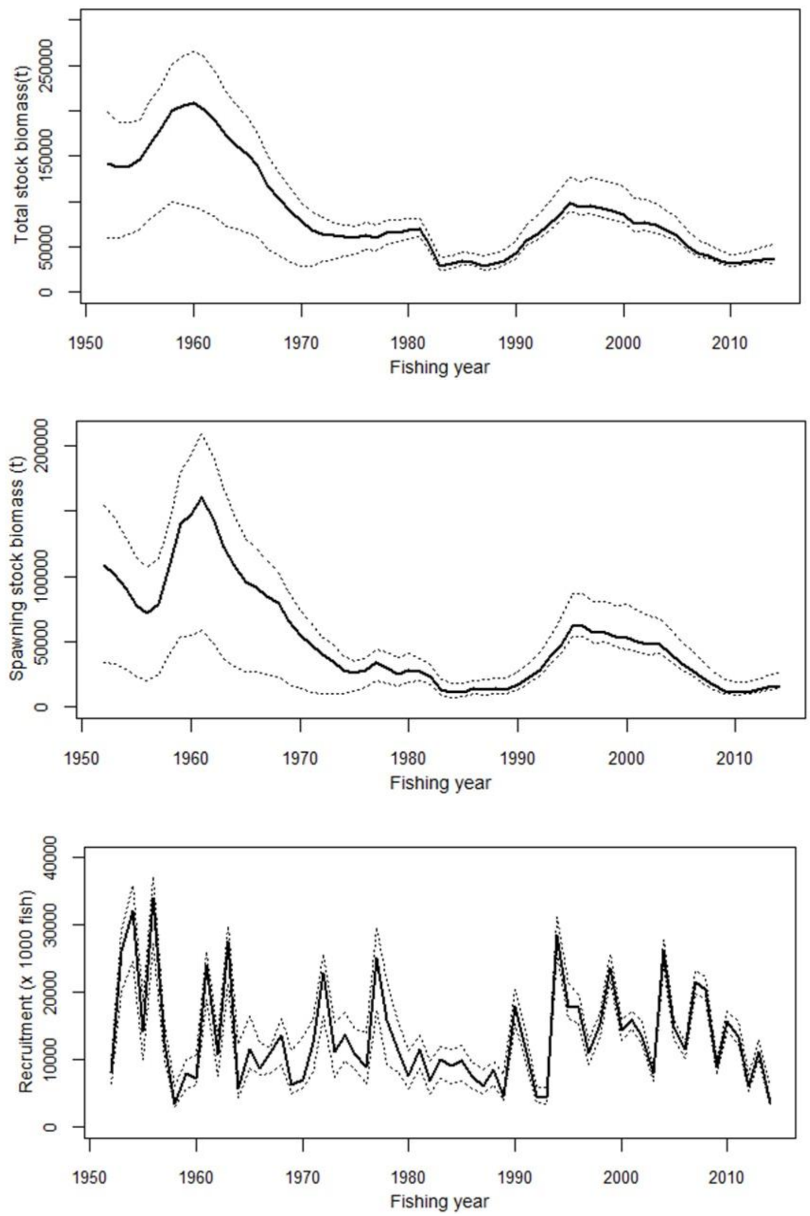



**Figure 7-4** Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of PBF from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

Recruitment estimates fluctuate widely without an apparent trend. The 2014 recruitment was relatively low, and the average recruitment for the last five years may have been below the historical average level (Figure 7-4). It should be noted that recruitment in terminal years of any assessment are highly uncertain due to limited information on the cohorts and this holds true for the 2016 assessment. However, two of the last three data points from the Japanese troll CPUE-based index of recruitment, which was consistent with other data in the model, are at their lowest level since the start of the index (1980). Estimated age-specific fishing mortalities on the stock during 2011-2013 and 2002-2004 (the base period for WCPFC CMM 2015-04) are presented in

Figure 7-5. Most age-specific fishing mortalities (F) for intermediate ages (2-10 years) are substantially above F2002-2004 while those for age 0, as well as ages 11 and above are lower (Table 7-1).

**Table 7-1.** Percent change of estimated age-specific fishing mortalities of PBF from 2002-2004 to 2011-2013.

| Age | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| change from F2002-2004 to F2011-2013 | -28% | -1% | +96% | +4% | +86% | +43% | -9% | +81% | +21% | +23% | +5% | -5% | -7% | -8% | -9% | -10% | -10% | -10% | -11% | -11% | -11% |

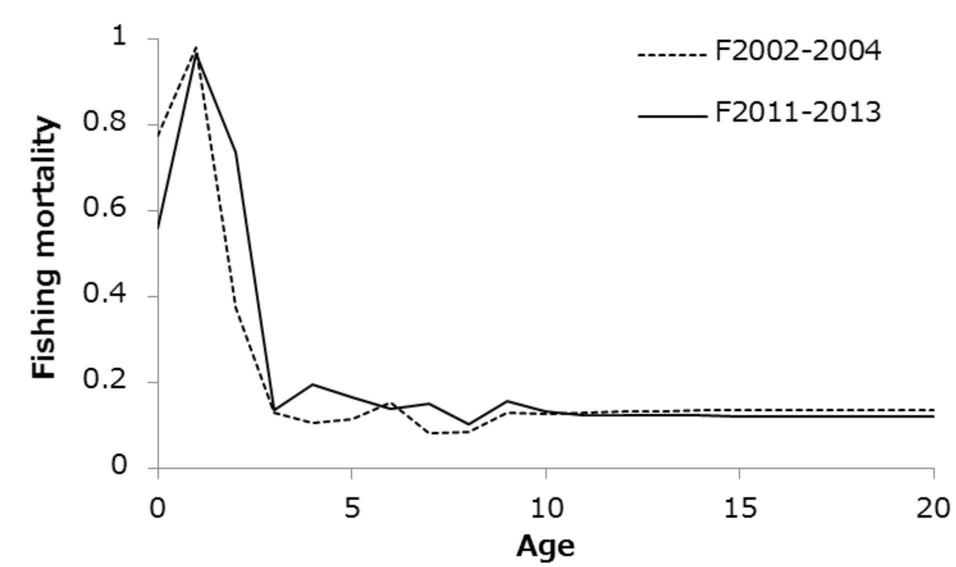



**Figure 7-5.** Geometric means of annual age-specific (years) fishing mortalities of PBF for 2002-2004 (dashed line) and 2011-2013 (solid line).

**Although no limit reference points have been established for the PBF stock under the auspices of the WCPFC and IATTC, the F2011-2013 exceeds all calculated biological reference points except for FMED and FLOSS despite slight reductions to F in recent years (Table 7-2). The ratio of SSB in 2014 relative to the theoretical unfished[2] SSB (SSB2014/SSBF=0, the depletion ratio) is 2.6%[3] and SSB2012/SSBF=0 is 2.1% indicating a slight increase from 2012 to 2014.** Although the SSB2014/SSBF=0 for this assessment (2.6%) is lower than SSB2012/SSBF=0 from the 2014 assessment (4.2%), this difference is due to improvements in the input data and model structure rather than a decline in SSB from 2012 to 2014. Note that potential effects on Fs as a result of the measures of the WCPFC and IATTC starting in 2015 or by other voluntary measures are not yet reflected in the data used in this assessment. [2. "Unfished" refers to what SSB would be had there been no fishing.
3. The unfished SSB is estimated based upon equilibrium assumptions of no environmental or density-dependent effects.]

Since no reference points for PBF have yet been agreed to at present, two examples of Kobe plots (Figure 7-6: plot A based on SSBMED and FMED, plot B based on SSB20% and SPR20%) are presented. These versions of the Kobe plot represent two interpretations of stock status in an effort to prompt further discussion. In summary, if these were the reference points, the stock would be approaching overfishing status in the case of FMED and the stock would be considered overfished. Plot B shows that the stock has remained in overfished and being-overfished status for the vast majority of the assessment period if F20% and SSB20% were chosen as reference points. The ISC notes that the SSB estimates before 1980 are more uncertain and that the reason why the fishing mortality is estimated to be so high right after the WWII is not well understood. The low biomass level at the beginning of the assessment period could potentially be the result of relatively high catches prior to the assessment period of PBF.

**Table 7-2.** Ratios of the estimated fishing mortalities F2002-2004, F2009-2011 and F2011-2013 relative to computed F-based biological reference points and SSB (t) and depletion ratio for the terminal year of the reference period for PBF.

| | $F_{max}$ | $F_{0.1}$ | $F_{med}$ | $F_{loss}$ | $F_{10\%}$ | $F_{20\%}$ | $F_{30\%}$ | $F_{40\%}$ | Estiamted SSB for terminal year of each reference period | Depletion ratio for terminal year of each reference period |
|---|---|---|---|---|---|---|---|---|---|---|
| 2002-2004 | 1.86 | 2.59 | 1.09 | 0.80 | 1.31 | 1.89 | 2.54 | 3.34 | 41,069 | 0.064 |
| 2009-2011 | 1.99 | 2.78 | 1.17 | 0.85 | 1.41 | 2.03 | 2.72 | 3.58 | 11,860 | 0.018 |
| 2011-2013 | 1.63 | 2.28 | 0.96 | 0.70 | 1.15 | 1.66 | 2.23 | 2.94 | 15,703 | 0.024 |

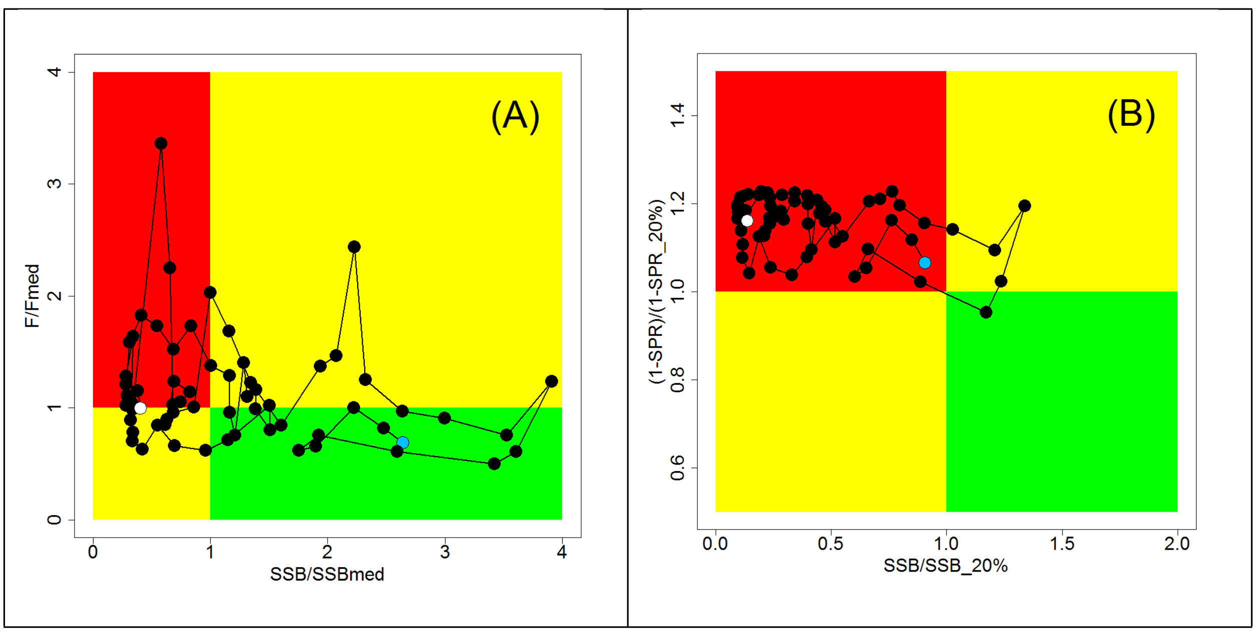
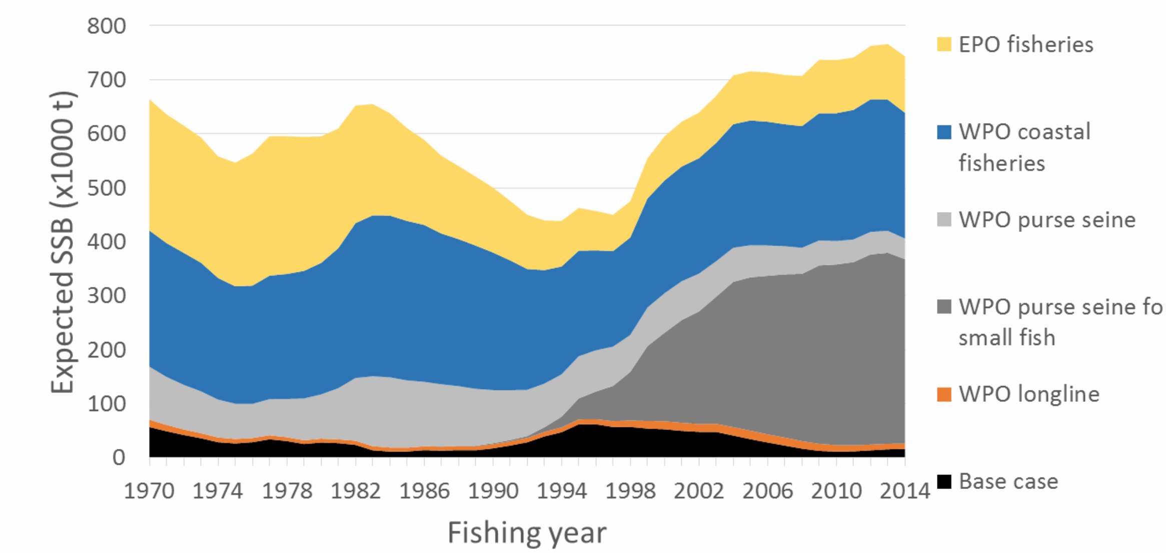



**Figure 7-6** Kobe plots for PBF. (A) SSBMED and FMED; (B) SSB20% and SPR20%. Note that SSBMED is estimated as the median of estimated SSB over whole assessment period (40,944 t) and FMED is calculated as an F to provide SSBMED in long-term, while the plots are points of estimates. The blue and white points on the plot show the start (1952) and end (2014) year of the period modeled in the stock assessment, respectively.

Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (age 0-1), have had a greater impact, and the effect of these fleets in 2014 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period (Figure 7-7). This is because the impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.



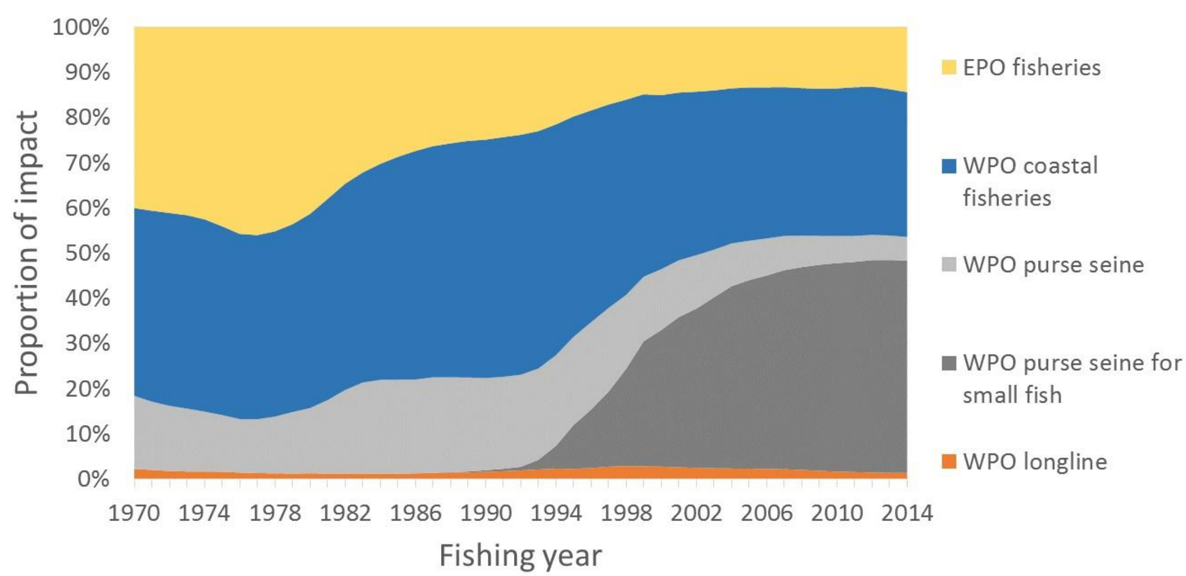




**Figure 7-7.** Trajectory of the spawning stock biomass of a simulated population of PBF when zero fishing mortality is assumed and recruitment series at F=0 is the same as estimated in the assessment, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse seine for small fish: F2, F3, F18. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15.

**Conservation Advice**

The steady decline in SSB from 1996 to 2010 appears to have ceased, although SSB2014 is near the historic low and the stock is experiencing exploitation rates above all calculated biological reference points except for FMED and FLOSS.

The projection results based on the base-case model under several harvest and recruitment scenarios and time schedules are shown in Table 7-3 and Figure 7-8. Under all examined scenarios the initial goal of WCPFC, rebuilding to SSBMED by 2024 with at least 60% probability, is reached and the risk of SSB falling below SSBLOSS at least once in 10 years was low.

The projection results indicate that the probability of SSB recovering to the initial WCPFC target (SSBMED by 2024, 38,000 t, calculated in the same manner as the previous assessment) is 69% or above the level prescribed in the WCPFC CMM if low recruitment scenario is assumed and WCPFC CMM 2015-04 and IATTC Resolution C-14-06 continue in force and are fully implemented (Table 4: Scenario 2 with low recruitment).

The ISC notes that there are technical inconsistencies in the calculation of SSBMED in the assessment and projection. The ISC also notes that the current calculation of SSBMED in the projection incorporates the most recent estimates of SSB and unless a fixed period of years is specified to calculate SSBMED, its calculation (SSBMED) could be influenced by future trends in spawning biomass. The ISC therefore recommends defining SSBMED as the median point estimate for a fixed period of time, either, 1952-2012 or 1952-2014. If 1952-2012 is chosen, then SSBMED is estimated to be 41,069 t, and if 1952-2014 is chosen, SSBMED is 40,994 t. The probabilities of achieving 41,000 t under various scenarios are provided in Table 7-3. The probabilities of achieving 43,000 t, where WCPFC CMM2015-04's initial rebuilding target is specified as 42,592 t, are also provided in Table 7 3, although this value is derived from the previous assessment and is higher than the SSBMED calculated in the current assessment. The ISC recommends that in the future absolute values should not be used for the initial rebuilding target, as the calculated values of reference points would change from assessment to assessment. Scenario 2 with low recruitment has the lowest prospect of recovery among the examined harvest scenarios. The probability of achieving the WCPFC's initial target (SSBMED by 2024) would increase if more conservative management measures were implemented as shown in Table 7-3 and Figure 7-8. The projection results indicate that a 10% reduction in the catch limit for fish smaller than the weight threshold in CMM 2015-04 would have a larger effect on recovery than a 10% reduction in the catch limit for fish larger than the weight threshold. (Figure 7-8 (D)). The ISC further notes that the current assessment model uses a maturity ogive that assumes 20%, 50% and 100% maturity in age 3 (weight on July 1: 34kg), 4 (weight on July 1: 58kg) and 5 (weight on July 1: 85kg), respectively, while the WCPFC CMM 2015-04 specifies that catches of fish smaller than 30kg should be reduced. The weight threshold in the CMM needs to be increased to 85kg (weight of age 5) if the intent is to reduce catches on all juveniles according to the maturity ogive in the assessment.

The projections results assuming a stronger stock-recruitment relationship (where h=0.9) than in the assessment model (0.999) are not necessarily more pessimistic than the low recruitment scenario.

The projection results assume that the CMMs are fully implemented and are based on certain biological or other assumptions. In particular, the ISC noted the implementation of size based management measures need to be monitored carefully. If conditions change, the projection results would be more uncertain. Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment has on stock biomass, monitoring recruitment and SSB should be strengthened so that the recruitment trends can be understood in a timely manner.

| Harvesting Scenario # | Fishing mortality | Catch limit | | Threshold of Small/Large fish | Recruitment scenario | Probability that SSB is more than SSB median (38,000 tons) | | | Probability that SSB is more than 43,000 tons (SSBmed@last assessment) | | | Probability that SSB is more than 10%SSB0 | | | Probability that SSB is more than 20%SSB0 | | | Average Catch | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Small fish | Large fish | | | 2024 | 2029 | 2034 | 2024 | 2029 | 2034 | 2024 | 2029 | 2034 | 2024 | 2029 | 2034 | 2019 | 2024 |
| Scenario1 | F2002-2004 | scenario 6 in 2014 assessment | | 30 kg | Low recruitment | 77.0% | 88.8% | 89.9% | 64.3% | 79.3% | 81.9% | 14.7% | 28.0% | 31.8% | 0.0% | 0.0% | 0.1% | 11619.2 | 13574.9 |
| Scenario2 | | 50% of 2002-2004 average catch for WPO fisheries, 3,300 tons for EPO commercial fisheries* | 2002-2004 average catch for WPO fisheries | | Low recruitment | 69.3% | 83.7% | 86.6% | 56.1% | 73.9% | 79.0% | 13.6% | 29.3% | 35.4% | 0.1% | 0.4% | 0.6% | 11749.7 | 12994.2 |
| | | | | | Average recruitment | 99.6% | 100.0% | 100.0% | 99.3% | 100.0% | 100.0% | 96.3% | 99.8% | 100.0% | 73.8% | 95.0% | 98.0% | 12958.4 | 14750.8 |
| | | | | | Stock Recruit Relationship w/ h=0.9 | 98.2% | 99.8% | 99.9% | 97.5% | 99.7% | 99.9% | 93.5% | 99.4% | 99.9% | 72.0% | 97.3% | 99.6% | 13087.3 | 15020.1 |
| Scenario3 | | 50% of 2002-2004 average catch for WPO fisheries, 2,750 tons for EPO commercial fisheries* | | 50 kg | Low recruitment | 80.5% | 91.5% | 94.0% | 69.1% | 85.1% | 88.5% | 22.2% | 43.6% | 51.7% | 0.2% | 0.9% | 1.3% | 11404.4 | 12672.3 |
| Scenario4 | | | | 80 kg | Low recruitment | 86.4% | 94.6% | 96.5% | 76.6% | 90.0% | 93.0% | 27.8% | 51.8% | 61.3% | 0.2% | 1.1% | 1.6% | 11292.6 | 12542.7 |
| Scenario5 | | 90% of scenario 2 | same as Scenario 2 | 30 kg | Low recruitment | 90.0% | 96.5% | 98.1% | 81.5% | 93.4% | 95.9% | 35.0% | 61.7% | 70.4% | 0.3% | 2.5% | 3.7% | 11306.4 | 12881.3 |
| | | | | | Average recruitment | 99.9% | 100.0% | 100.0% | 99.9% | 100.0% | 100.0% | 98.4% | 100.0% | 100.0% | 82.2% | 97.8% | 99.3% | 12442.0 | 14126.3 |
| | | | | | Stock Recruit Relationship w/ h=0.9 | 99.4% | 100.0% | 100.0% | 99.1% | 100.0% | 100.0% | 97.0% | 99.8% | 100.0% | 81.8% | 99.0% | 99.9% | 12576.4 | 14448.2 |
| Scenario6 | | same as Scenario 2 | 90% of scenario 2 | | Low recruitment | 75.3% | 88.2% | 90.2% | 61.7% | 78.6% | 83.4% | 15.7% | 32.5% | 38.7% | 0.1% | 0.5% | 0.7% | 11496.2 | 12632.4 |
| | | | | | Average recruitment | 99.7% | 100.0% | 100.0% | 99.5% | 100.0% | 100.0% | 96.8% | 99.9% | 100.0% | 75.1% | 95.2% | 98.1% | 12686.3 | 14071.5 |
| | | | | | Stock Recruit Relationship w/ h=0.9 | 98.9% | 99.9% | 100.0% | 98.4% | 99.9% | 100.0% | 95.0% | 99.7% | 100.0% | 75.5% | 98.0% | 99.9% | 12761.0 | 14379.7 |
| Scenario7 | | 90% of scenario 2 | | | Low recruitment | 90.3% | 96.8% | 98.3% | 82.7% | 94.2% | 96.8% | 39.4% | 68.0% | 77.4% | 0.5% | 3.5% | 5.6% | 11231.0 | 12607.1 |
| | | | | | Average recruitment | 99.9% | 100.0% | 100.0% | 99.9% | 100.0% | 100.0% | 98.5% | 100.0% | 100.0% | 83.5% | 98.1% | 99.6% | 12139.4 | 13461.7 |
| | | | | | Stock Recruit Relationship w/ h=0.9 | 99.2% | 100.0% | 100.0% | 99.0% | 99.9% | 100.0% | 96.9% | 99.8% | 100.0% | 81.6% | 99.0% | 99.9% | 11227.3 | 12461.8 |
| Scenario8 | | 80% of scenario 2 | same as Scenario 2 | | Low recruitment | 97.5% | 99.6% | 99.9% | 94.8% | 98.9% | 99.5% | 65.4% | 89.2% | 94.0% | 1.9% | 14.5% | 22.8% | 10922.8 | 12688.4 |
| Scenario9 | | same as Scenario 2 | 80% of scenario 2 | | Low recruitment | 78.1% | 89.9% | 92.5% | 65.0% | 81.9% | 86.3% | 18.4% | 37.1% | 44.7% | 0.2% | 0.6% | 0.9% | 11327.0 | 12329.9 |
| Scenario10 | | 80% of scenario 2 | | | Low recruitment | 98.3% | 99.8% | 99.9% | 96.3% | 99.5% | 99.8% | 73.2% | 93.8% | 97.5% | 3.1% | 22.4% | 34.1% | 10585.9 | 11586.4 |
| | | | | | Average recruitment | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 99.7% | 100.0% | 100.0% | 91.0% | 99.5% | 100.0% | 11194.1 | 12104.9 |
| | | | | | Stock Recruit Relationship w/ h=0.9 | 99.8% | 100.0% | 100.0% | 99.7% | 100.0% | 100.0% | 98.7% | 100.0% | 100.0% | 90.0% | 99.7% | 100.0% | 11227.3 | 12461.8 |
| Scenario11 | F2011-2013 | same as Scenario 2 | same as Scenario 2 | | Low recruitment | 82.6% | 93.0% | 95.0% | 71.3% | 86.4% | 89.9% | 23.6% | 46.2% | 56.0% | 0.1% | 1.2% | 1.6% | 12266.8 | 13587.4 |

* Catch limits for EPO commercial fisheries is applied for all the catch (small and large fish) made by the Fleets.

** Average recruitment referres to the recruitment for the whole assessment period while low recruitment referres to that of 1980-1989.

**Table 7 3.** Future projection scenarios for PBF and their probability of achieving various target levels by various time schedules based on the base-case model.
* Catch limits for EPO commercial fisheries is applied for all the catch (small and large fish) made by the Fleets. ** Average recruitment refers to the recruitment for the whole assessment period while low recruitment refers to that of 1980-1989. *** Probability that SSB exceeds 41,000 tons (SSB median of Basecase model) developed by PBFWG at ISC16 Plenary.14

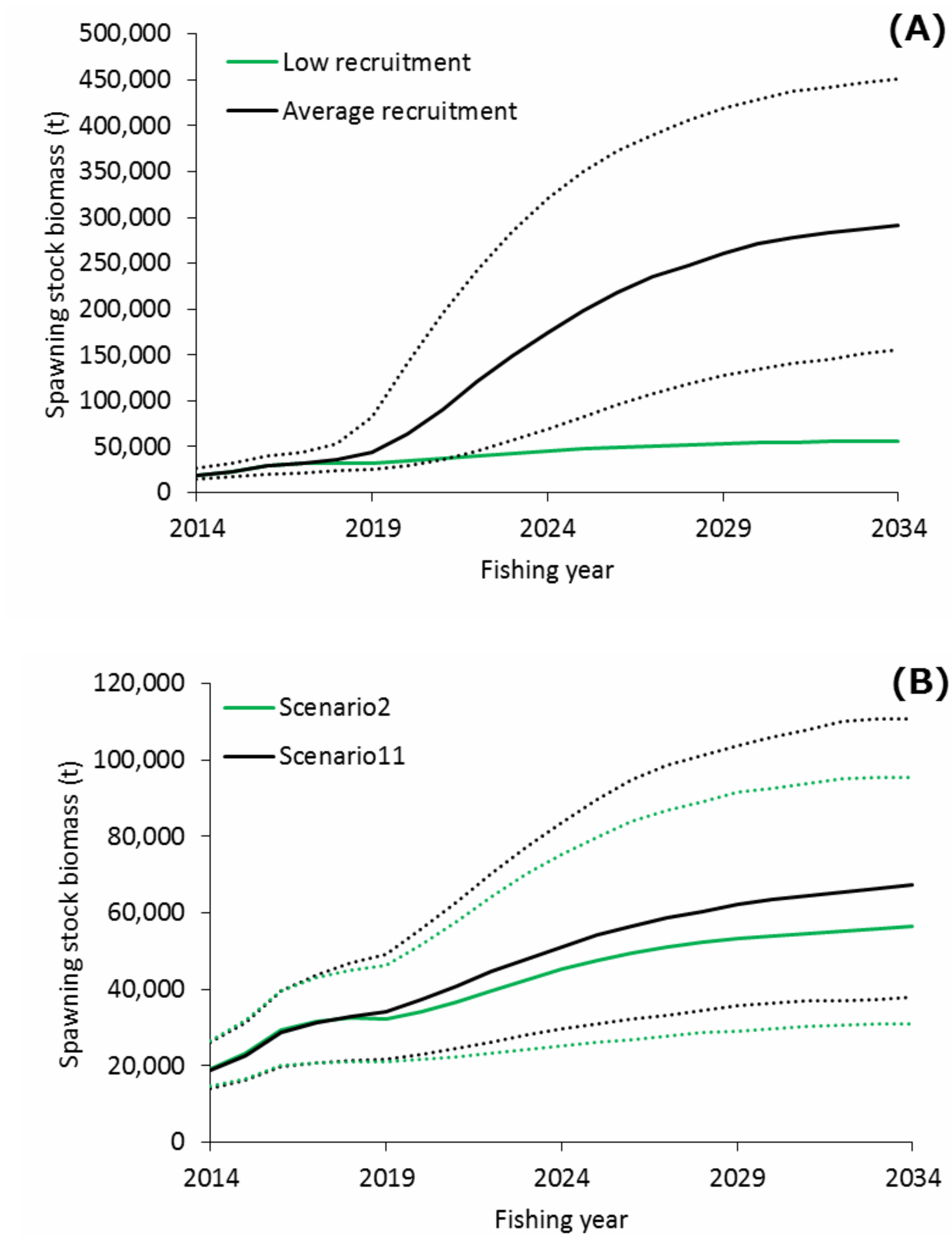
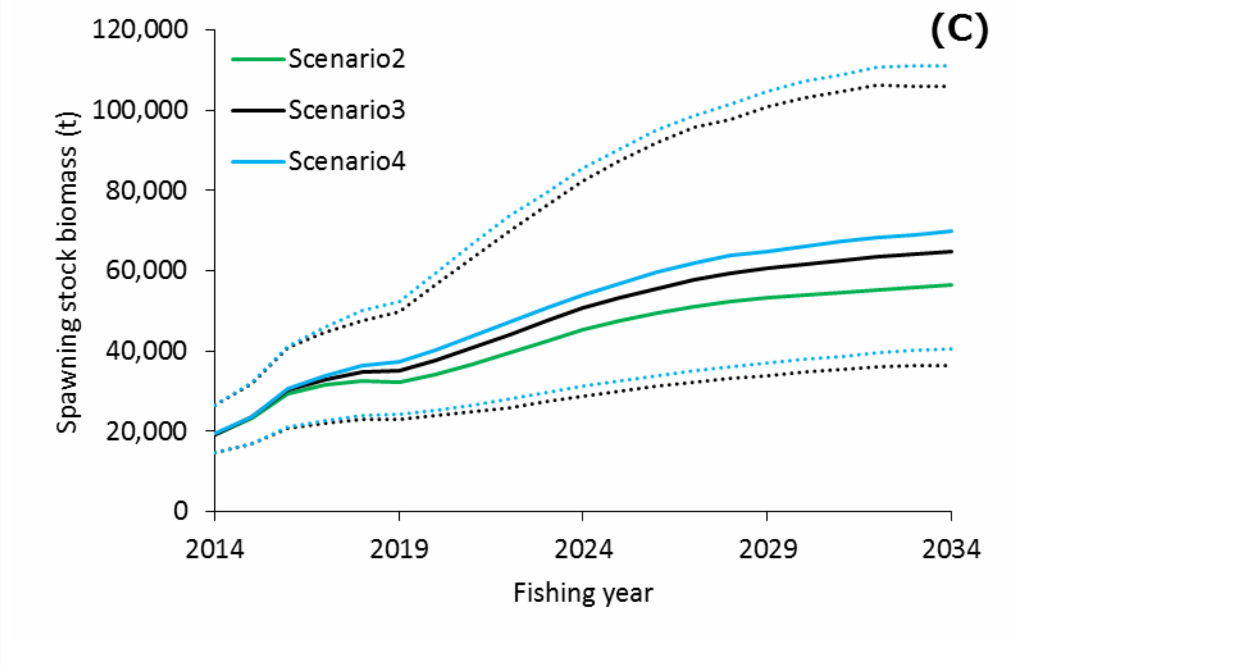



**Figure 7-8.** Comparisons of various projection results for PBF. (A) low recruitment vs. historical average recruitment (Scenario 2). (B) current CMMs (Scenario 2) vs. current F (Scenario 11) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.



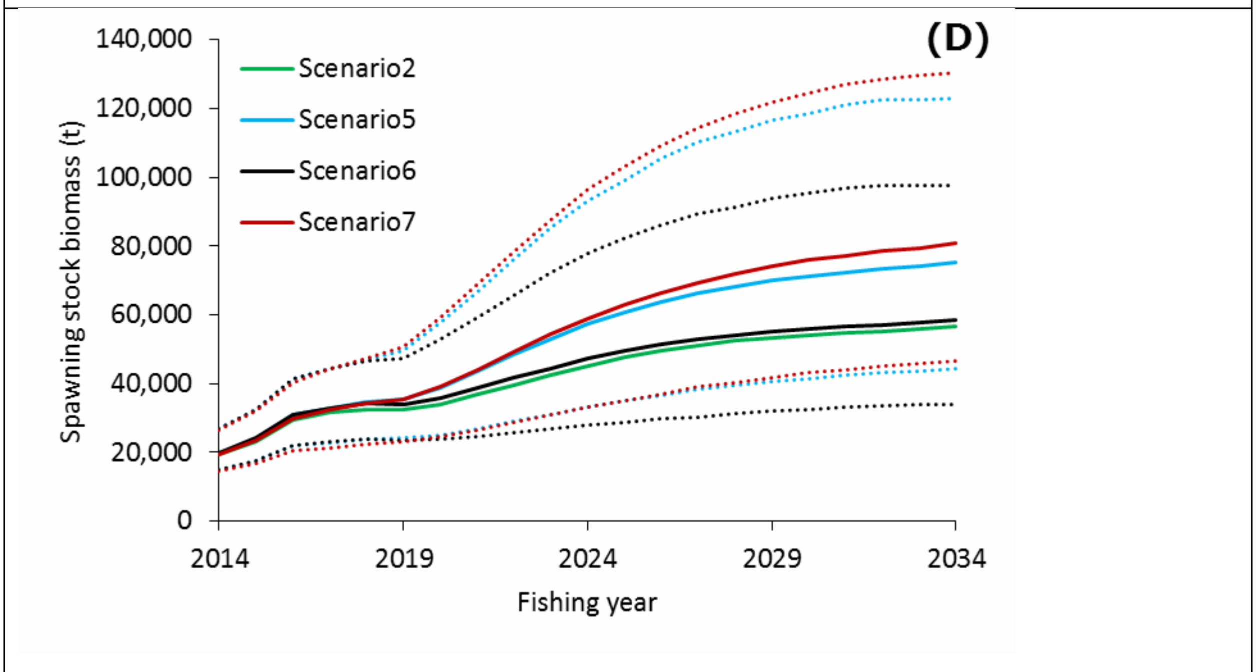




**Figure 7-8 (cont.)** Comparisons of various projection results for PBF. (C) different definition of small fish (30kg (Scenario 2) vs. 50kg (Scenario 3) vs. 80kg (Scenario 4)) (low recruitment). (D) current CMMs (Scenario 2) vs. additional 10% catch limit reduction for small fish (Scenario 5), for large fish (Scenario 6) and for all fish (Scenario 7) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.

## 6. ESA SECTION 4(a)(1) INDIVIDUAL THREAT ANALYSIS

### 6.1 Evaluation of Individual Threats

The SRT considered the best available information in its analyses of the severity of threats to the PBF population. All threats evaluated by the SRT were based on the assumption that current regulations and management practices were in effect and employed throughout the time periods considered (see below). The SRT agreed that regulations and management practices are likely to change in the future, however using current regulations represented the best available information. The SRT also evaluated all threats based on current rather than historical activities. The SRT acknowledged that the historical effects of the threats evaluated contributed to current PBF population levels, however the charge of the SRT was to evaluate threats as they currently affect or are projected to affect the PBF population.

The threats considered by the SRT were those listed in the statutory ESA Section 4(a)(1)(A)-(E) factors considered in listing determinations as well as additional threats listed in the petition or considered as important by the SRT. The SRT evaluated these threats over a short and long timescale (over the next 25 years and 100 years; see section 1.5 for additional comments on timescales).

Threats were evaluated in terms of the severity and certainty associated with each. Severity and certainty levels were scored as a numeric value corresponding to high, moderate, low or none (as defined below) by each SRT member.

**Level of Severity:** The level of risk that this threat is likely to contribute to the decline or degradation of the PBF population over each time frame (over the next 25 years and 100 years). Specific rankings for severity are defined as follows:

- **3** = **High:** The threat is likely to *eliminate or seriously degrade* the PBF population.
- **2 = Moderate:** The threat is likely to *moderately degrade* the PBF population.
- **1 = Low:** The threat is likely to *only slightly impair* the PBF population.
- **0 = None:** The threat is *not likely to impact* the PBF population.

**Level of Certainty:** The level of certainty that the threat is affecting, or is likely to affect, PBF populations over the time frame considered. Specific rankings for certainty are defined as follows:

- **3 = High:** There is *definitive* published and/or unpublished data to support the conclusion that this threat is affecting, or is likely to affect, the PBF population with the severity ascribed over the timeframe considered.
- **2 = Moderate:** There is *some* published and/or unpublished data to support the conclusion that this threat is affecting, or is likely to affect, the PBF population with the severity ascribed over the timeframe considered .
- **1 = Low:** There is *little* published and/or unpublished data to support the conclusion that this threat is affecting, or is likely to affect, the PBF population with the severity ascribed over the timeframe considered.

- **0 = None:** There is no published or unpublished data to support the conclusion that this threat is affecting, or is likely to affect, the PBF population with the severity ascribed over the timeframe considered.

Following the initial rankings of severity across all specific threats, the SRT identified those threats where the range of rankings across the SRT was greater than one. For these threats, subsequent discussions ensured that the interpretation of the threat and its time-frame were clear and consistent across team members. For example, it was necessary to clarify that threats were considered only as they related to existing management measures and not historical management. After clarification, and a final round of discussion, each team member provided a final set of severity rankings for each specific threat.

There were three specific threats (Illegal, Unregulated, and Unreported [IUU] fishing, International Management, and SST rise) for which the range of severity rankings remained greater than one following thorough discussion. For these threats the SRT carried out a Structured Expert Decision Making process (SEDM) to determine the final severity rank. In this SEDM approach, each team member was asked to apportion 100 plausibility points across the four levels of severity.  Points were totaled and mean scores were calculated. The severity level with the highest mean was determined to be the final ranking. Table 1 presents a generic example of the SEDM process. Full tables of severity and certainty rankings are presented in Appendix I a-b. A discussion of each individual threat is presented in the following sections.

Table 1. Generic example of the SEDM process. In this case, the mean scores were highest for ranking hypothetical Specific Threat #1 in category "1" in severity.

| Specific Threat #1 | Ranking | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| Team Member 1 | 25 | 50 | 20 | 5 |
| Team Member 2 | 15 | 20 | 50 | 15 |
| Team Member 3 | 20 | 50 | 20 | 10 |
| **Mean** | 20.00 | **40.00** | 30.00 | 10.00 |

## 6.2 The Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range.

### 6.2.1 Water Pollution

Given their highly migratory nature, PBF experience a wide range of water conditions throughout their life cycle.  Pollutants vary in terms of their concentrations and composition depending on location, with higher concentrations typically occurring in coastal waters.  There are two main classes of pollutants in the sea that are most prevalent and could pose potential risks to PBF: mercury and Persistent Organic Pollutants (POPs).  However, the SRT also considered Fukushima derived radiation and oil pollution as independent threats (see 6.2.3 and 6.6.2 below).

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation. POPs are most often derived from pesticides, solvents, pharmaceuticals, or industrial chemicals. Common POPs in the marine environmental include the organochlorine Dichlorodiphenyltrichloroethane (DDT) and Polychlorinated biphenyls (PCBs). Because they are not readily broken down and enter the food-web, POPs tend to bioaccumulate in marine organisms. In fishes, some POPs have been shown to impair reproductive function in fish very close to regions with high levels of contamination (e.g., white croaker; Cross, et al., 1988; Hose, et al., 1989).

Specific information on pollutants in PBF is limited. Ueno et al. (2002) examined the accumulation of POPs (e.g. PCBs, DDTs, and chlordanes (CHLs)) in the livers of PBF collected from coastal Japan. They determined, as expected, that the uptake of these organochlorines was driven by dietary uptake rather than through exposure to contaminated water (i.e., through the gills). This research showed that levels of organochlorines were positively and linearly correlated with body length. Body length normalized values for PCBs, DDTs, and CHLs were calculated as 530-2600 ng/g lipid weight, 660-800 ng/g lipid weight, and 87-300 ng/g lipid weight, respectively. More recently, Chiesa et al (2016) measured pollutants from PBF in the Western Central Pacific Ocean and found that 100% of the individuals sampled tested positive for five of the six PCBs assayed. Three POPs (specifically PBDEs) were detected in 5-60% of fish examined. Two organochlorines were detected in 30-80% of samples. Unlike the findings of Ueno et al (2002) from coastal Japan, no DDT or its end-products were detected in PBF in the Western Central Pacific Ocean.

While POPs have been detected in the tissues of PBF, much higher levels have been measured in other marine fish (e.g., Lyons et al. 2015). While there is a lack of direct experimentation on the potential impacts of POPs on PBF, there is no indication that they exist in levels that are harmful to PBF. The SRT concluded that they pose no to low risk to a decline or degradation of the PBF population.

Mercury (Hg) enters the oceans primarily through the atmosphere-water interface. Initial sources of Hg are both natural and anthropogenic. One of the main sources of anthropogenic Hg is coal-fired power-plants. Total Hg emissions to the atmosphere have been estimated at 6,500-8,200 Mg $yr^{-1}$, of which 4,600-5,300 Mg $yr^{-1}$ (~50-75%) are from natural sources (Driscoll et al., 2013).

In water, elemental Hg is converted to methyl-Hg by bacteria. Once methylated, Hg is easily absorbed by plankton and thus enters the marine food-web. As with POPs, Hg bioaccumulates and concentrations increase in higher trophic level organisms.

As a top predator, PBF can potentially accumulate high levels of Hg. Several studies have examined Hg in PBF and reported a wide range of concentrations that vary based on geographic location. In the WPO, measured Hg concentrations ranged from 0.66 – 3.23 µg/g wet mass (Hisamichi et al., 2010; Yamashita et al., 2005), whereas in the EPO they ranged from 0.31 – 0.508 µg/g wet mass (Lares et al. 2012; Coman et al., 2015). The latter study demonstrated that in the EPO individuals that had recently arrived from the WPO contained higher Hg concentrations than those that had resided in the EPO for 1-3 years, including wild-caught individuals being raised in net pens. By comparison, concentrations of Hg in Atlantic bluefin tuna have been measured at 0.25 – 3.15 mg/kg wet mass (Lee et al., 2016). Notably, Lee et al. (2016) demonstrated that Hg concentrations in Atlantic bluefin tuna declined 19% over an eight year period from the 1990s to the early 2000s, a result of reduced anthropogenic Hg emissions in North America. Tunas are also known to accumulate high levels of Selenium (Se) which is suggested to have a detoxifying effect on methyl-Hg compounds (reviewed in Ralston et al., 2016).

The petitioners suggest that since some bluefin products contain Hg concentrations above 1 ppm, the U.S. Food and Drug Administration's (FDA) threshold, there is cause for concern with regards to bluefin health. The FDA levels are set at the point at which consumption is not recommended for children and women of child bearing age and are not linked to fish health. While methyl Hg compounds have been shown to cause neurobiological changes in a variety of animals, there have been no studies on tuna or tuna-like species showing detrimental effects from methyl Hg. As with the POPs, other marine species have much higher levels of Hg contamination (Montiero and Lopes, 1990; Lyons et al., 2015).

The SRT was unanimous in the determination that Hg contamination does not pose a direct threat to population decline or degradation in PBF. While the SRT acknowledged that bioaccumulation of pollutants in PBF may result in some risk to consumers, the absence of empirical studies showing that water pollution had direct effects on PBF implies that water pollution is not a high risk for PBF themselves.

#### 6.2.2 Plastic Pollution

Plastics have become a major source of pollution on a global scale and in all major marine habitats (Law, 2017). In 2014, global plastic production was estimated to be 311 million metric tons (Plast. Eur. 2015). Plastics are the most abundant material collected as floating marine debris or from beaches (Law, et al., 2010; Law, 2017) and are known to occur on the seafloor. Impacts on the marine environment vary with type of plastic debris. Larger plastic debris can cause entanglement leading to injury or death, while ingestion of smaller plastic debris has the potential to cause injury to the digestive tract or accumulation of indigestible material in the gut. Studies have also shown that chemical pollutants may be adsorbed into plastic debris which would provide an additional pathway for exposure (e.g., Chua et al., 2014).

Small plastics (microplastics) have been documented as the primary source of ingested plastic materials among fish species, particularly opportunistic planktivores (e.g., Rochman et al., 2013; 2014; Matsson et al., 2015). Few studies have examined microplastic ingestion by larger predatory fishes such as PBF and results from these studies are mixed.

Cannon et al. (2016) found no evidence of plastics in the digestive tracts of skipjack tuna (*Katsuwonis pelamis*) and blue mackerel (*Scomber australensis*) in Tasmania. Choy and Drazen (2013) found no evidence of plastic ingestion in skipjack (*K. pelamis*) or yellowfin tuna (*Thunnus albacares*) in Hawaiian waters, but found that ~33% of bigeye tuna (*Thunnus obesus*) had anthropogenic plastic debris in their stomachs. While no specific studies on plastic ingestion in PBF are available, a study of foraging ecology in the EPO found no plastic in over 500 stomachs examined from 2008-2016 (O. Snodgrass, NMFS, unpublished data).

The SRT considered plastic ingestion by PBF to have no to low impact on population decline or degradation in PBF. This was based in large part upon the absence of empirical evidence of large amounts of macro- and micro-plastic directly impacting individual PBF health.

### 6.2.3 Oil and Gas Development

There are numerous examples of oil and gas exploration and operations posing a threat to marine organisms and habitats. Threats include seismic activities during exploration and construction and events such as oil spills or uncontrolled natural gas escape where released chemicals can have severe and immediate effects on wildlife.

Unfortunately there is limited information on the direct impacts of oil and gas exploration and operation on pelagic fishes such as PBF. Studies looking at the impacts of seismic exploration on fish have mixed results. Wardle et al (2001) and Popper et al (2005) documented low to moderate impacts on behavior or hearing, whereas McCauley et al (2003) reported long-term hearing loss from air-gun exposure. Risk associated with seismic exploration would likely be less of a concern for highly migratory species that can move away and do not use sounds to communicate. Reduced catch rates in areas for a period of time after air guns have been used are considered evidence for this avoidance behavior in a range of species (Popper and Hastings 2009).

The effects of seismic exploration on larval PBF could be greater than on older individuals due in part to the reduced capacity of larvae to move away from affected areas. Davies et al. (1989) stated that fish eggs and larvae can be killed at sound levels of 226-234 decibel (dB), which are typically found at 0.6 - 3.0 meters (m) from an air gun such as those used during seismic exploration. Visual damage to larvae can occur at 216 dB, levels found ~5 m from the air gun. Less obvious impacts such as disruptions to developing organs are harder to gauge and are little explored in the scientific literature, however severe physical damage or mortality appears to be limited to larvae within a few meters of an air gun discharge (Dalen et al. 1987; Patin & Cascio 1999).

The most relevant study, for the purposes of the SRT, is an evaluation of the impacts of oil pollution on the larval stage of Atlantic bluefin tuna. Oil released from the 2010 Deepwater Horizon oil spill in the Gulf of Mexico covered ~10% of the spawning habitat prompting concerns about larval survival (Muhling et al 2012). Modeled western Atlantic bluefin tuna recruitment for 2010 was low compared to historical values, but it is not yet clear whether this was primarily due to oil-induced mortality, or unfavorable oceanographic conditions (Domingues et al. 2016). Results from laboratory studies showed that exposure to oil resulted in significant defects in heart development in larval Atlantic bluefin tuna (Incardona et al. 2014) with a likely reduction in fitness. A similar response would be expected in PBF. Consequently, an oil spill in or around the spawning grounds has the potential to impact larval survival of PBF. Previous spills near to the spawning grounds have mostly been from ships (e.g. Varlamov et al. 1999; Chiau 2005), and have resulted in much smaller, more coastally confined releases into the marine environment than from the Deepwater Horizon incident. However, offshore oil exploration has increased in the region in recent years, potentially increasing the risks of a large-scale spill. Despite these considerations, the overall risks to PBF associated with an oil spill were considered by the SRT to be low for a number of reasons; 1) Large oil spills are rare events, 2) PBF larvae are spread over two spawning grounds with little oceanographic connectivity between them, reducing risk to the population as a whole, 3) the population is broadly dispersed overall, and 4) an acute spill would likely only affect a single year of recruitment.

Oil and gas infrastructure may have beneficial impacts on the marine environment by providing habitat for a range of species and *de facto* no fishing zones. California has been a prime area of research into the effects of decommissioned oil platforms. Claisse et al. (2014) showed that some offshore oil platforms in California rank among the highest measured fish production of any habitat in the world, exceeding even coral reefs and estuaries. Caselle et al (2002) showed that even remnant oil field debris (e.g., defunct pipe lines, piers, and associated structures) harbored diverse fish communities. This pattern is not unique to California. For example, Fabi et al. (2004) showed that fish diversity and richness increased within the first year after installation of two gas platforms in the Adriatic Sea, and that biomass of fishes on these platforms was substantial. Consequently, oil platforms may provide forage and refuge for PBF.

While the SRT acknowledged that oil and gas development has the potential to cause negative impacts on marine organisms, and acute contamination events may have especially high impact on PBF larvae, the SRT considered oil and gas development to have no to low risk to population decline or degradation in PBF, although with low certainty.

### 6.2.4 Wind Energy Development

Concerns about climate impacts linked to the use of petroleum products has led to an increase in renewable energy programs over the past two decades. Offshore and coastal wind energy generating stations have been among the fastest growing renewable energy sectors, particularly in shallow coastal areas which generally have consistent wind patterns and reduced infrastructure costs due to shallow depths and proximity to land.

Impacts of wind energy generating stations on marine fauna have been well studied (see Köppel, 2017 for examples). There have been some studies predicting negative effects on marine life, particularly birds and benthic organisms, however few empirical studies have demonstrated direct impacts to fishes. Wilson et al. (2010) reviewed numerous papers discussing the impacts of wind energy infrastructure and concluded that while they are not environmentally benign, the impacts are minor and can often be ameliorated by proper placement.

Studies on wind energy development and its impact on fishes has largely focused on demersal species assemblages. Similar to oil and gas platforms, wind energy platforms have been shown to have a positive effect on demersal fish communities in that they tend to harbor high diversity and biomass of fish populations (e.g., Wilhelmsson et al. 2006). Following construction of "wind farms", one particular concern has been the effects of noise created by the operating mechanisms on fish. Wahlberg and Westerberg (2005) concluded that wind farm noise does not have any destructive effects on the hearing ability of fish, even within a few meters. The major impact of the noise is largely restricted to masking communication between fish species which utilize sounds (Wahlberg and Westerberg, 2005). Given that PBF are not known to use sounds for communication, the impact of noise would be minimal if any. Additionally, wind farms are likely to serve as de facto fish aggregating devices and may prove beneficial at attracting prey and thus PBF as well. Also, given the highly migratory nature of PBF and their broad range, wind farms would not take up a large portion of their range and could be avoided.

The SRT considered wind energy development to pose no or very low risk to population decline or degradation in PBF. This was based largely on the ability of PBF to avoid wind farms and the absence of empirical evidence showing harm directly to PBF.

### 6.2.5 Large-Scale Aquaculture (Habitat Destruction)

Operation of coastal aquaculture facilities can degrade local water quality, mostly through uneaten fish feed and feces leading to nutrient pollution. The severity of these issues depends on the species being farmed, food composition and uptake efficiency, fish density in net pens, and the location and design of pens (Naylor et al. 2005). There are several offshore culture facilities throughout the world, most being within 25 km of shore.
The petition by CBD highlights a proposed offshore aquaculture facility in California, USA, as a potential threat to PBF. The proposed Rose Canyon aquaculture project would construct a facility to raise yellowtail jack approximately 7 km from the San Diego coast. The high capacity of the proposed project (reaching up to 5,000 metric tons annually after eight years of operation) has raised concerns about resulting impacts to the surrounding marine environment. As the proposed aquaculture facility would act as a point source of pollutants, the potential impacts to widely distributed pelagic species such as PBF will depend on oceanographic dispersal of these pollutants within the Southern California Bight (SCB) and surrounding regions.

Data from current meters and Acoustic Doppler Current Profilers (ADCPs) near to Point Loma have recorded seasonally reversing, and highly variable, alongshore flows (Hendricks 1977; Carson et al. 2010). However, cross-shelf currents were much weaker. Similarly, Lahet & Stramski (2010) showed that river plumes in the San Diego area identified by satellite ocean color imagery moved variably north or south along the coast until dispersing, but were not advected offshore. Recent studies using high-resolution simulations of a regional oceanic modeling system have also shown limited connectivity between the nearshore region off San Diego and the open SCB (Dong et al. 2009; Mitari et al. 2009). This suggests that uneaten food and fecal matter resulting from the proposed Rose Canyon aquaculture facility would likely be dispersed along the southern California and northern Baja California coasts rather than offshore. PBF are distributed throughout much of the California Current ecosystem, and are often caught more than 100 km from shore (Holbeck et al. 2017). Tagging studies have also shown very broad habitat use of PBF offshore of Baja California and California (Boustany et al. 2010). It should be noted that any aquaculture facilities in the U.S. are subjected to rigorous environmental reviews and standards prior to being permitted. Outside of California, culture facilities would likely have similar, limited impacts on PBF.

The SRT thus considered that habitat degradation from large-scale aquaculture posed no to low risk to population decline or degradation in PBF over both time-scales largely due to the very small proportion of their habitat which would be impacted as well as the absence of empirical evidence showing harm directly to PBF.

### 6.2.6 Prey depletion

As highly migratory, fast-swimming top predators, tunas have relatively high energy requirements (Olson & Boggs 1986; Korsmeyer & Dewar 2001; Whitlock et al. 2013; Golet et al. 2015). They fulfill these needs by feeding on a wide range of vertebrate and invertebrate prey, the relative contribution of which varies by species, region and time period. PBF in the California Current ecosystem have been shown to prey on forage fish such as anchovy, as well as squid and crustaceans (Pinkas et al. 1971; Snodgrass et al. unpublished data). As commercial fisheries also target some of these species, substantial removals could conceivably reduce the prey base for predators such as PBF. Previous studies have used trophic ecosystem models to show that high rates of fishing on forage species could adversely impact other portions of the ecosystem, including higher-order predators (Smith et al. 2011; Pikitch et al. 2012).
Biomass of the two main forage fish in the California Current, sardine and anchovy, has been low in recent years (Lindegren et al. 2013; Lluch-Cota 2013). This likely represents part of the natural cycle of these species, which appear to undergo frequent “boom and bust” cycles, even in the absence of industrial-scale fishing (Schwartzlose et al. 1999; McClatchie et al. 2017). PBF appear to be generalists and consequently are less impacted by these shifts in abundance than a specialist would be. Pinkas et al. (1971) found that PBF diets in the late 1960s were >80% anchovy, coinciding with a period of relatively high anchovy biomass. In contrast, more recent data from the 2000s show a much higher dominance of squid and crustaceans in PBF diets, with high interannual variability (Snodgrass et al. unpublished data). Neither study recorded a substantial contribution of sardine to PBF diets, however both diet studies (Pinkas et al., Snodgrass et al. unpublished data) were conducted during years in which sardine biomass was comparatively low.

This ability to switch between prey species may be one reason why Hilborn et al. (2017) found little evidence that forage fish population fluctuations drive biomass of higher order consumers, including tunas. This disconnect is clear for PBF. For example, in the 1980s, PBF biomass and recruitment were both very low, but forage fish abundances in both the California Current and Kuroshio-Oyashio ecosystems were high (Lindegren et al. 2013; Yatsu et al. 2014). Hilborn et al. (2017) considered that a major weakness of previous trophic studies was a lack of consideration of this strongly fluctuating nature of forage fish populations through time. Predators have thus likely adapted to high variability in abundance of forage fish and other prey species by being generalists.

Although PBF have a broad and varied prey base in the California Current, the physiological effects of switching between dominant prey types are not well known. Some species are more energy-rich than others, and may have lower metabolic costs to catch and digest (Olson & Boggs 1986; Whitlock et al. 2013). Fluctuations in the energy content and size spectra of a prey species may also be important, as was found for the closely-related Atlantic bluefin tuna (Golet et al. 2015). It is therefore not yet clear how periods of strong reliance on anchovy vs. invertebrates, for example, may impact the condition and fitness of PBF. As PBF range throughout most of the North Pacific, interactions between feeding conditions in the California Current and those on other foraging areas may be important, but are not well understood. For example, abundances of forage fish species have also varied strongly in the past several decades on feeding grounds in the waters off eastern Japan. Biomass of sardine, anchovy and Pacific saury have generally varied out of phase, with sardine most abundant between the regime shifts which occurred in ~1976 and 1988, and anchovy and saury at low abundance during this time (Yatsu et al. 2014).

The SRT considered that prey depletion posed no to low risk to population decline or degradation in PBF over the 25 year time frame, primarily because empirical evidence shows that they are generally adapted to natural fluctuations of forage fish biomass through prey switching. However, the SRT considered that prey depletion may pose a low to moderate risk to population decline or degradation in PBF over the 100 year timeframe, albeit with low certainty. This was mainly because climate change is expected to alter ecosystem structure and function to produce potentially novel conditions, over an evolutionarily short time period. If this results in a less favorable prey base for PBF, in either the California Current or other foraging areas, impacts on the population may be more deleterious than they have been in the past.

## 6.3 Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

### 6.3.1 Illegal, Unregulated, and Unreported (IUU) Fishing

Illegal, Unreported and Unregulated (IUU) fishing is a broad term which includes:

- Fishing and fishing-related activities conducted in contravention of national, regional and international laws.
- Non-reporting, misreporting or under-reporting of information on fishing operations and their catches.
- Fishing by "Stateless" vessels.
- Fishing in convention areas of Regional Fisheries Management Organizations (RFMOs) by non-party vessels.
- Fishing activities which are not regulated by nations and cannot be easily monitored and accounted for.

IUU fishing is an acknowledged problem on a global scale. The United Nations Food and Agricultural Organization (FAO) estimates that 11-26 million tons of fish are taken in as IUU products at a value of $10-23 million USD each year. These unreported catches can lead to underestimates of the total removals, which are used in stock assessment and may therefore lead to bias in estimates of fishing mortality and stock size. Accounting for this bias in stock assessment is very challenging because it depends on both of the magnitude of such catches and time series of these catches relative to the official catches. If the proportion of unreported catch relative to the official catches is constant over time, the impact on estimates of the current depletion level for the stock assessment is less than that of the current stock size. It is likely that if this portion is decreasing or increasing, both the current depletion level and the current stock size would be underestimated.

While there is likely some level of IUU fishing for PBF in the Pacific, no reports of substantial IUU fishing have emerged, thus the amount cannot be determined. However, improvements to catch document schemes in several countries have been proposed/implemented in an effort to combat IUU harvest and the most recent advice from the relevant RFMOs requires improvements to reporting. A majority of the SRT considered that the magnitude of potential IUU fishing losses for PBF were likely low relative to existing commercial catches and thus not likely to increase substantially in the future, however the certainty around this determination is low.

One member of the SRT considered that IUU fishing could potentially affect PBF in its current state that may be dependent on a small number of adult year classes. In this member's view, management of high-seas fisheries has proven difficult. This member pointed out that new markets in countries near to adult spawning grounds are developing and illegal wildlife trade, including trade of fisheries products, are also on the increase.

Given the absence of estimates of IUU fishing losses for PBF, the SRT had a low level of certainty for this threat. However, given the continued improvements in CDSs and the assumption of low IUU take relative to the commercial harvest, the SRT determined that IUU fishing represented a low to moderate risk to population decline or degradation in PBF.

### 6.3.2 Recreational Fishing

Recreational fishing for PBF occurs to some extent in most areas where PBF occur relatively close to shore. The majority of reported recreational effort appears to be by the U.S. fleet, although this may be an artifact of a lack of record keeping outside of the U.S. From the mid-1980s onward, the majority of U.S. PBF landings have been from recreational fisheries. The recreational fishing fleet along the west coast of the U.S. for highly migratory species such as PBF is comprised of commercial passenger fishing vessels (CPFVs) and privately owned vessels operating from ports in southern California (Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species, as amended [July 2011], Appendix A). The CPFV fleet is highly active, employing more than 1,500 full-time equivalent workers in 2013 (Stohs 2016). Direct expenditures on recreational fishing trips from southern California ports amounted to $119 million on CPFV trips in 2013 (Stohs 2016).

The vast majority of these vessels operate from ports in southern California from Los Angeles south to the U.S./Mexico border, with a large proportion operating out of San Diego. Much of the catch occurs in Mexican waters. The recreational catch for PBF is dominated by hook and line fishing with a very small contribution from spear fishing. The landings for PBF are highly variable (Figure x). This variability is linked to changes in the number of young fish that move from the western Pacific (Bayliff 1994), and potentially regional oceanographic variability, and is not taken to reflect changes in overall Pacific-wide abundance.

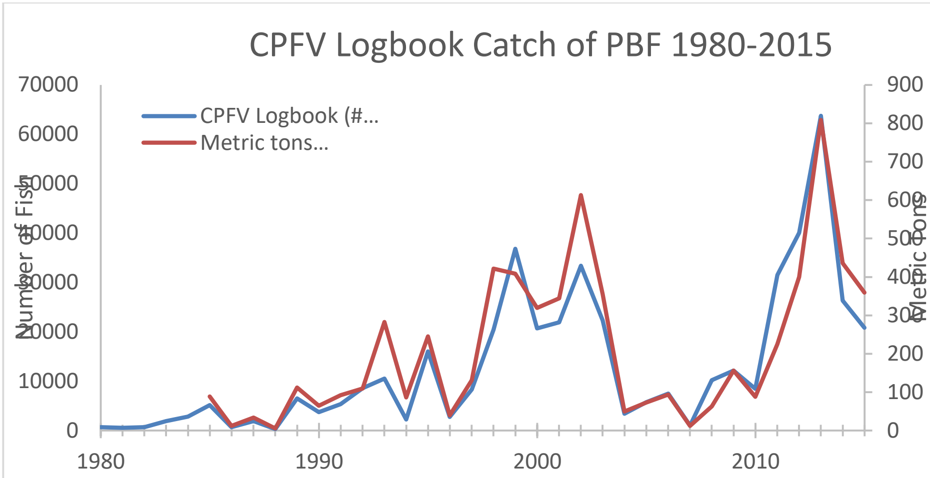



**Figure 5. California Commercial Passenger Fishing Vessel logbook reported landings (individuals and estimated biomass) 1980-2015.**

In addition to variability in immigration to the EPO, regulatory measures impact the number of fish caught. As mentioned, most U.S. fishing effort occurs in Mexican waters. In July 2014, Mexico banned the capture of PBF in its EEZ for the remainder of the year, reducing the catch by the U.S. recreational fleet. The ban was lifted in 2015, and, in response to IAATC resolution C-14-06 #5 calling for equal cuts in sport fisheries as to those in commercial catches, the U.S. and Mexico simultaneously instituted a two fish per angler per day bag limit on PBF, lowered from 10 fish per angler per day in previous years. This also acted to reduce catch. The lower values of CPFV logbook catches from 2014 and 2015 were not necessarily caused by a lower abundance of PBF in the EPO, but more likely by the more restrictive regulations.

Since 1980, the peak of the U.S. recreational fishery was in 2013 when 63,702 individual fish were reported in CPFV log books with an estimated weight of 809 mt (Fig. 5). This was more than the total U.S. commercial catch in 2013 (10.1 mt) keeping in mind that commercial vessels cannot go into Mexican waters. The average recreational catch is far lower (264 mt average from 2006-2015; 2006 being the first peak in landings). As compared to the global catch, the peak recreational CPFV landings in the U.S. in 2013 represented 7% of the total global catch of PBF in that same year whereas in 2015 it represented 3.2% of total global catch.

Private vessel landings are harder to quantify as they rely on voluntary interviews with fishers at only a few of the many landing ports. In 2015, the estimated landings by private vessels was 6,195 individual PBF. These landings are not included in the CPFV logbook counts above and represent additional landings.

The SRT evaluated the potential threat of recreational fishing in light of the following:

- Present and historic recreational take of PBF in relation to the global commercial landings
- Current and past management of the recreational PBF fishery

- Gear selectivity of the fishery (low bycatch, size selectivity towards smaller fish)
- Age of individuals taken by the fishery

At 3.2% of the total global landings, the SRT considered the U.S. recreational fishery as a minor overall contributor to the global catch of PBF and recent measures have been implemented to reduce landings. Given that recreational landings have been reduced through increased management, the SRT considered recreational fishing as posing no or a low risk to population decline or degradation in PBF.

### 6.3.3 Commercial Fishing

Commercial fishing for PBF has occurred in the western Pacific since at least the late 1800s. Records from Japan indicate that several methods were used prior to 1952 when catch records began to be taken in earnest and included longline, pole and line, drift net, and set net fisheries. Estimates of global landings prior to 1952 peaked around 47,635 mt (36,217 t in the WPO and 11,418 t in the EPO) in 1935 (Muto et al. 2008). After 1935 landings dropped in response to a shift in maritime activities caused by World War II. Fishing activities expanded across the North Pacific Ocean after the conclusion of the war and landings increased consistently for the next decade prior to becoming more variable (Muto et al. 2008). Figure 6 depicts the estimated Pacific-wide landings of PBF for the period 1891-2011 from Muto et al. (2008).

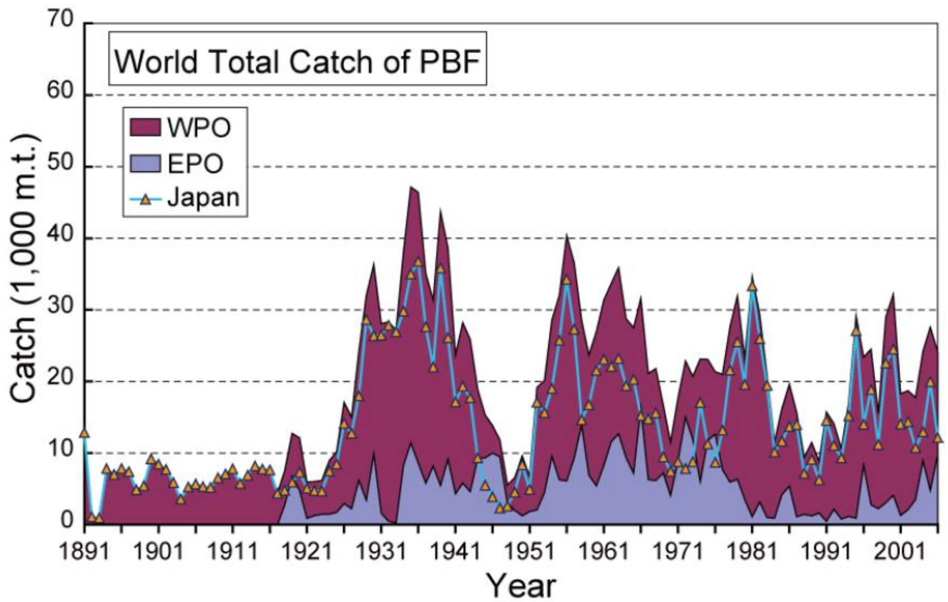



**Figure 6. Global landings of PBF 1891-2011 (Muto, et al., 2008).**

There are currently five major contributors to the PBF fisheries: Japan, Korea, Mexico, Taiwan, and the United States (U.S.). Each operates in nearshore coastal waters in the Pacific Ocean while a few also operate in distant offshore waters. In modern fisheries, PBF are taken by a wide range of fishing gears (e.g. longline, purse seine, set net, troll, pole-and-line, drift nets, and hand line fisheries), which target different size classes (see below). Among these fisheries, purse seine fisheries are currently the primary contributor to landings, with the Japanese fleet being responsible for the majority of the catch. Much of the global purse-seine catch supports commercial grow-out facilities where fish aged ~1-3 are kept in floating pens for fattening prior to sale.

Estimates of landings indicate that annual catches of PBF by country have fluctuated dramatically from 1952-2015. During this period reported catches from the five major contributors to the ISC peaked at 40,144 t in 1956 and reached a low of 8,627 t in 1990 with an average of 21,955 mt. Japanese fisheries are responsible for the majority of landings followed by Mexico, the U.S., Korea and Taiwan (Figure 7). In 2014, the U.S. reported commercial landings of 408 mt, Taiwan reported 525 mt, Korea reported 1,311 mt, Mexico reported 4,862 mt, and Japan reported 9,573 mt. These represent 2.4%, 3%, 7.7%, 28.4%, and 56% of the total landings, respectively. Landings in the southern hemisphere are small and concentrated around New Zealand.

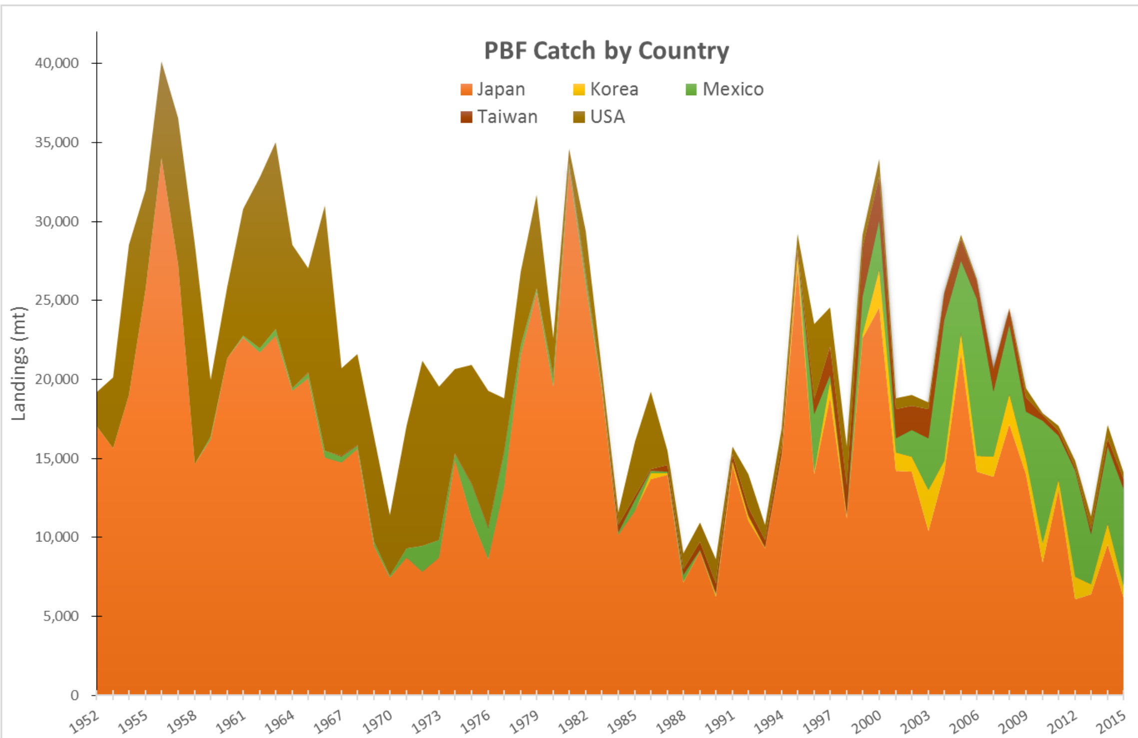



**Figure 7. Global landings of PBF (mt) by country 1952-2014 (ISC, 2016).**

The commercial Japanese PBF fisheries are comprised of both distant-water and coastal longline vessels, coastal trolling vessels, coastal pole-and-line vessels, coastal set net vessels, coastal hand line vessels, and purse seiners. Each fishery targets specific age classes of PBF: coastal trolling and pole and line target fish less than one year old, coastal set net and coastal hand-line target ages 1-5, purse seiners target ages 0-10, and the distant-water and coastal longline vessels target ages 5-20. The distant water longline fisheries have operated for the longest time while the coastal longline fisheries did not begin in earnest until the mid-1960s. Between 1952 and 2015, total annual catches by Japanese fisheries have fluctuated between a maximum of ~34,000 mt in 1956 and a minimum of ~6,000 mt in 2012 and have averaged 15,653 mt.

The Japanese troll fleet harvests small, age-0 PBF for its commercial aquaculture grow-out facilities. From 2005-2015, the harvest of PBF for grow-out by the troll fishery has averaged 14% of Japan's total landings (~8.5 % of global landings) by weight.

Nearly all commercial PBF catches by U.S. flagged vessels on the west coast of the U.S. are landed in California. Historically, the commercial fisheries for PBF focused their efforts on the fishing grounds off Baja California, Mexico, until the 1980s. Following the creation of Mexico's EEZ, the U.S. purse seine fisheries largely ceased their efforts in Mexico and became more opportunistic (Aires-da-Silva et al. 2007). Since 1980, commercial landings of PBF have fluctuated dramatically, averaging 859.2 mt with two peaks in 1986 (4,731.4 mt) and 1996 (4,687.6 mt). The low catch rates are not caused by the absence of PBF (a similar situation to U.S. recreational catches), but rather the absence of a dedicated fishery, low market price and the inability to fish in the Mexican EEZ. In 2014, commercial landings of PBF in the U.S. were 408 mt, representing 2.4 % of the total global landings. Figure 8 shows commercial PBF landings from 1982-2016 and the long-term mean.

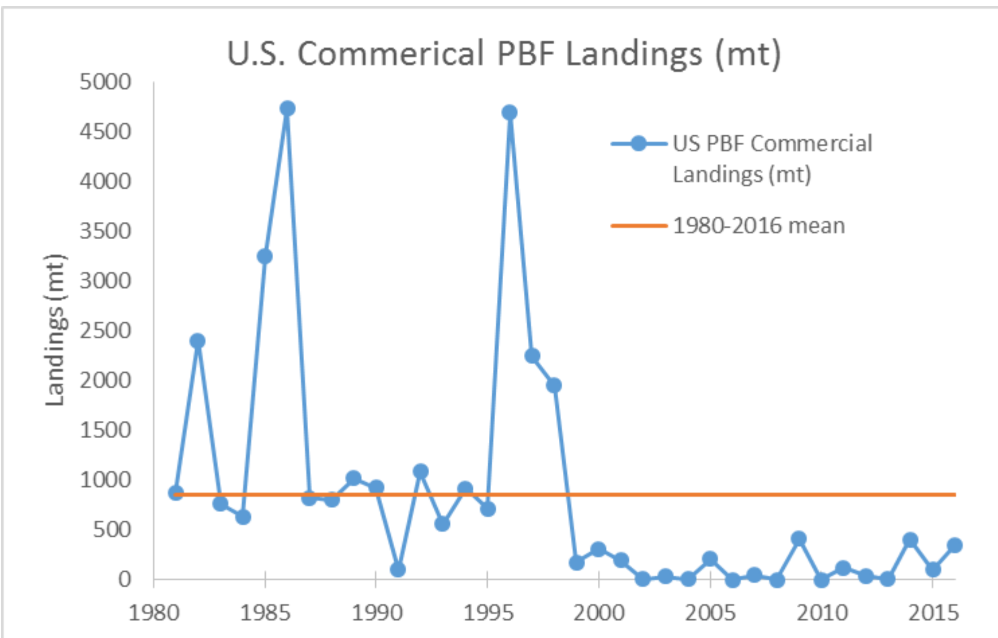



**Figure 8. United States commercial landings of PBF (mt) 1980-2015.**

Mexico's harvest of PBF is dominated by its purse seine fisheries, which dramatically increased in size following the creation of Mexico's EEZ. While most of the purse seine fisheries target yellowfin tuna (the dominant species in the catch) in tropical waters, PBF are caught by purse seine near Baja California. Since 1952, reported landings in Mexico have ranged from 1- 9,927 mt with an average of 1,766.7 mt (data not reported for 1952-1958, 1960, 1992, and 1993). Since grow-out facilities began in Mexico, (1997) the purse seine fishery for PBF almost exclusively supports these facilities. These facilities take in age 1-3 PBF and "fatten" them in floating pens for export and represent virtually all of Mexico's reported capture of PBF. From

2005-2015, Mexico's harvest for its grow-out facilities has averaged 26.8 % of the global landings.

The Korean take of PBF is dominated by its offshore purse seine fishery with a small contribution by the coastal troll fisheries. The fisheries generally operate off Jeju Island with occasional forays into the Yellow Sea (Yoon et al. 2014). The purse seine fisheries did not fully develop until the mid-1990s and landings were below 500 mt prior to this. Landings gradually increased and peaked at 2,601 mt in 2003, but have declined since then with 676 mt landed in 2015. Since 1952, the average reported Korean landings of PBF has been 535 mt (data not reported from 1952-1971).

Historically, the Taiwanese fisheries have used a wide array of gears, however since the early 1990s the fisheries are largely comprised of small-scale longline vessels. These vessels are targeting fish on the spawning grounds near the Ryukyu Islands. The highest reported catch was in 1990 at 3,000 mt, however landings declined to less than 1,000 mt in 2008 and to their lowest level of about 200 mt in 2012. Landings have since increased and the preliminary estimate of PBF landings in 2015 was 542 mt. Since 1952, Taiwanese landings of PBF have averaged 658 mt.

While there is a high degree of variability, overall, PBF commercial landings have shown a general decline since 1952. Of particular note is the dramatic increase in landings of age-0 PBF (Fig. 9). Since ~1994, landings of age-0 PBF have fluctuated but persist at nearly triple the tonnage from 1952 to 1993. In the past decade, a concerted effort has been made to ameliorate the effects of a large market demand and high landings, however commercial fishing remains the largest source of PBF mortality among the threats examined in this report.

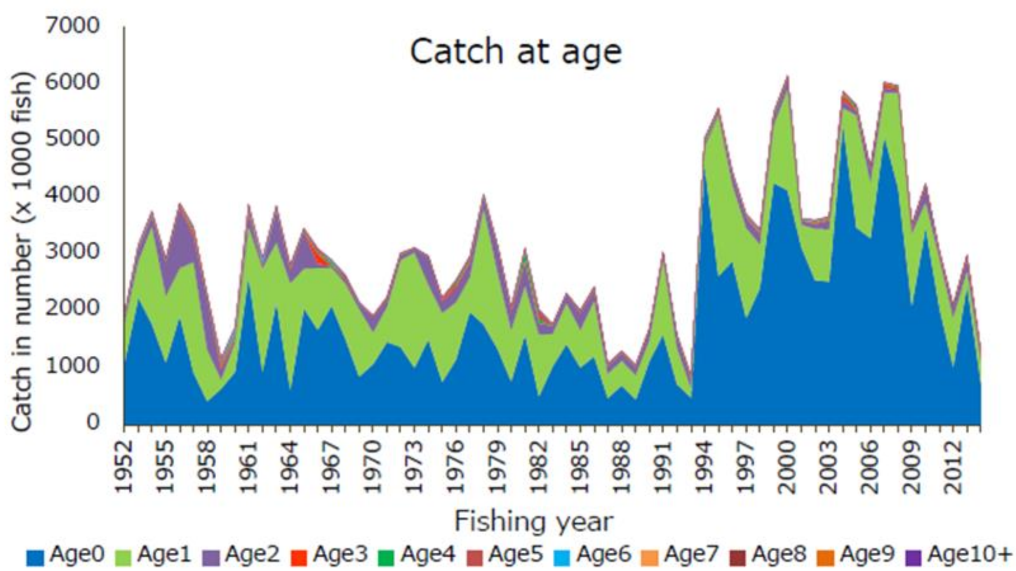



**Figure 9. Global landings of PBF by age class (1000's of individuals; ISC, 2016).**

The SRT acknowledges the Petition's concern that a large proportion of PBF caught are between 0 and 2 years of age. The petition states that 97.6% of fish are caught before they have a chance to reproduce, and argues that this is a worrisome example of growth overfishing. The interpretation of the severity of this statement requires acknowledging several factors that are used to evaluate the production (amount of "new" fish capable of being produced by the current stock) which are missing from the petition. Importantly, the estimate of production includes considering factors such as recruitment, growth of individuals (thus moving from one age class to the next and potentially reach sexual maturity), catch, and natural mortality. Excluding all other parameters except catch results in erroneous interpretations of the severity of a high proportion of immature fish being landed on an annual basis.

As an example, we can lengthen the time over which we estimate the proportion of immature fish landed to evaluate the potential negative effects. Table 2 shows the 2014 estimated landings per age class from age 0-4, the 2014 estimated population size in each age class, and the catch as a percentage of the total estimated population size. Also shown are landings data adjusted for the estimates of percent maturity for age classes three and four (20% and 50%, respectively). That is, 80 % of landings of age three fish are expected to have not had a chance to reproduce, and 50% of landings of age four fish will not have had a chance to reproduce.

**Table 2. Pacific bluefin tuna landings (in # x 1000) represented as total catch per age class, catch per age class adjusted for immature individuals, estimated population size for each age class, and adjusted catch as a percent of the total. All data are from the terminal year of the ISC stock assessment (2014).**

| | Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Total |
|---|---|---|---|---|---|---|
| Catcth per age class | 733.4 | 381.0 | 71.6 | 79.6 | 10.1 | 1275.7 |
| Catcth per age class(adj.) | 733.4 | 381.0 | 71.6 | 63.4 | 5.1 | 1254.4 |
| 2014 Estimated Pop. Size | 750.2 | 398.6 | 184.6 | 164.5 | 35.8 | 1533.6 |
| Adj. Catch as % of total | 97.8 | 95.6 | 38.8 | 38.5 | 14.1 | 81.8 |

As is presented in the table above, if all year classes are taken into account, the percentage of fish in the entire population (not just in the age 0 age class) that are harvested before reaching maturity is closer to ~82%. The SRT acknowledges that this is not an ideal harvest target, however it is a more accurate representation of the catch of immature fish.

Growth overfishing occurs when the average size of harvested individuals is smaller than the size that would produce the maximum yield per recruit. The effect of growth overfishing is that total yield (i.e., population size) is less than it would be if all fish were allowed to grow to a larger size. Reductions in yield per recruit due to growth overfishing can be ameliorated by reducing fishing mortality (i.e., reduced landings) and/or increasing the average size of harvested fish, both of which have been recommended by the relevant RFMOs and adopted by participating countries fishing PBF (see section 6.5).

The SRT considered commercial fishing to be the greatest threat to the decline or degradation of the PBF population. Threat scores for commercial fishing ranged from moderate to high (severity score of 2 to 3 with a mean of 2.29; see Appendix Ia-b). While the SRT acknowledged that past trends in commercial landings have been the largest contributor to the decline in the PBF population, it considered the population in the terminal year of the ISC stock assessment (2014; >1,625,000 individuals and >143,000 spawning capable individuals) as sufficient to prevent extinction. This is due to the fact that the population size is large enough to prevent small population effects (e.g., allee effects) from having negative consequences (see section 6.7 for a discussion of small population effects). The SRT also acknowledged that none of the scenarios evaluated in the ISC stock projections showed declining trends. This likely indicates that the proposed reductions in landings in the ISC stock assessment which were adopted by the relevant RFMOs and have been implemented by participating countries are likely to prevent future declines. However, should the proposed reductions not be met, future population declines may occur. Therefore, the SRT considered commercial fishing to post a moderate to high risk to the degradation of the PBF population.

### 6.3.4 Scientific and Educational Use

PBF are utilized in scientific research for a range of studies such as migration patterns, stable isotope analysis, and feeding preference. The amount of lethal use of PBF in scientific and educational pursuits is negligible as most tissues used in research (e.g. otoliths, muscle samples) are sourced from fish already landed by fishers. The SRT found no evidence that this poses a threat to the decline or degradation of the PBF population.

### 6.3.5 Large-Scale Aquaculture Effects

Large-scale aquaculture operations involving PBF are conducted in two ways: "Ranching", where small PBF are taken from the wild and grown to marketable size in pens, and closed-cycle culture whereby broodstock are maintained to provide spawn which are raised through the larval and juvenile stages to market size. Both of these activities have the potential to increase the risk of degradation of the PBF population. Many of these potential risks are more appropriately included in other section 4(a)(1) categories and have been treated in other sections of the report as described below.

Ranching operations have direct impacts on the PBF population by removing individuals from the population. These removals are recorded as commercial landings in the catch documentation schemes for Japan and Mexico, the two countries primarily engaged in this activity for PBF. The potential impacts from these activities are discussed and risks evaluated in section 6.3.3.

Ranching operations may also indirectly impact the PBF population. Parasites or other pathogens that may be more common in high-density pens could spread to wild PBF. This is discussed in section 6.4.2. Another indirect impact may manifest itself in that prey species are removed from the wild to feed captive PBF which may reduce prey availability to wild fish. Potential impacts of prey depletion are discussed and risks evaluated in section 6.2.6.

Closed-cycle aquaculture has far less potential to impact the PBF population beyond the initial collection of the few individuals retained as brood stock. The largest potential impact on the PBF would be accidental release of individuals to the environment which has the potential to impact natural levels of genetic diversity leading to changes in adaptability or changes in the natural genetic population structure. These impacts can be mitigated if the broodstock population has similar genetic diversity and the wild population and that the diversity is maintained if non-wild individuals are used as broodstock. In addition, if the severity of the release (number/frequency) is low, potential alterations to natural populations will be low.

The limited genetic data on PBF suggest that the population is a well-mixed and genetically diverse population (Tseng et al., 2012; Nomura et al., 2014). Given that the broodstock currently being used in closed-cycle systems are wild fish, this level of diversity is expected to be present in their offspring, thus any escape of these offspring would be no different than if they were spawned in the wild.

The SRT acknowledges that as closed-cycle aquaculture develops there is potential for brood stock to be comprised of non-wild individuals, and through successive generations inbreeding depression (causing loss of genetic diversity) may manifest. Currently, however, there is neither information that the broodstock or offspring populations are genetically compromised nor is there information on the severity of unintentional releases of PBF.

## 6.4 Predation and Disease

### 6.4.1 Predation

As large predators, PBF are not heavily preyed upon naturally after their first few years. Predators of adult PBF may include marine mammals such as Killer Whales (*Orcinus orca*) or shark species such as White (*Carcharodon carcharias*) and Mako Sharks (*Isurus* spp.) (Nortarbartolo di Sciara, 1987; Collette and Klein-MacPhee, 2002; de Stephanis, 2004; Fromentin and Powers, 2005). Juvenile PBF may be preyed upon by larger opportunistic predators and, to a lesser degree, seabirds.

The SRT considered that natural predation posed no to low risk for population decline or degradation in PBF. This was based primarily on the limited diversity of predators and absence of empirical evidence showing abnormal decline/degradation of PBF by predation.

### 6.4.2 Disease

Studies of disease in PBF are largely absent from the literature. Most studies involve the identification of parasites normally associated with cage culture. Parasites are often associated with mortalities and reduced production among farmed marine fishes (Hayward *et al.,* 2007). Epizootic levels of parasites with short, direct, one-host life cycles, such as monogeneans, can be reached very quickly in cultured fish because of the confinement and proximity of these fish (Thoney and Hargis, 1991). Among wild marine fishes, parasites are usually considered benign, though they can be associated with reduced fecundity of their hosts (Jones, 2005; Hayward *et al.,* 2007).

Munday *et al.* (2003) provided a summary of metazoan infections (myxosporeans, *Kudoa* sp., monogeneans, blood flukes, larval cestodes, nematodes, copepods) in tuna species. Many metazoans infect *Thunnus* spp., but not many are known to cause mortalities; most studies to date have focused on the health and/or economic importance of these diseases. For example, postmortem liquefaction of muscle due to myxosporean infections occurs in albacore, yellowfin tuna, and bigeye tuna (*Thunnus obesus*), and in poorly identified *Thunnus* spp. Lesions caused by *Kudoa* sp. have been found in yellowfin tuna and southern bluefin tuna (Langdon, 1990; Kent *et al.*, 2001). Munday *et al.* (2003) report that southern bluefin tuna have been found to be infected with an unidentified, capsalid monogenean that causes respiratory stress but does not lead to mortality.

Young PBF are often infected with red sea bream iridovirus, but the disease never appears in Pacific bluefin tuna more than 1 year of age, and occurrence is restricted to periods of water temperatures > 24°C (Munday *et al.*, 2003). Mortality rates rarely reach greater than 10 percent for young fish. The fish either die during the acute phase of the disease, or they become emaciated and die later.

There is no evidence of transmission of parasites or other pathogens from captive PBF in tuna ranches. This is likely due to the fact that wild PBF are not likely to be in close enough proximity to pens used to house PBF.

The SRT determined that disease posed no to low risk to population decline or degradation in PBF. This was based largely on the absence of empirical evidence of abnormal levels of natural disease outbreaks in PBF, the absence of observations of wild PBF swimming in close enough proximity to "farms" such that disease transmission is possible, and due to the absence of empirical evidence showing disease transmission from "farms" to wild PBF.

### 6.5 Inadequacy of Existing Regulatory Mechanisms - Existing Regulatory Authorities, Laws and Policies

This section describes the current management and regulatory schemes for PBF. Overutilization of any resource is intrinsically tied to any management and regulatory scheme. This section describes the current schemes for PBF in consideration of recent changes in response to patterns of utilization discussed in section 6.3 above and in consideration of their adequacy or inadequacy to address high rates of PBF capture production.

The PBF fisheries are managed under the authorities of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), the Tuna Conventions Act of 1950 (TCA), and the Western and Central Pacific Fisheries Convention Implementation Act (WCPFCIA). The TCA and WCPFCIA authorize the Secretary of Commerce to implement the conservation and management measures of the Inter-American Tropical Tuna Commission (IATTC) and Western and Central Pacific Fisheries Commission (WCPFC), respectively.

### 6.5.1 International Management

PBF is managed as a single Pacific-wide stock under two regional fisheries management organizations (RFMOs): IATTC, which operates in the EPO, and WCPFC, which operates primarily in the western and central regions. Both RFMOs are responsible for establishing conservation and management measures based on the scientific information, such as stock status, obtained from the ISC.

The IATTC has scientific staff that, in addition to conducting scientific studies and stock assessments, also provides science-based management advice. After reviewing the PBF stock assessment prepared by the ISC and the analyses conducted by its own staff, the IATTC develops resolutions. Mexico and the United States are the two IATTC member countries that currently fish for, and have historically fished for, PBF in the EPO. Thus the IATTC resolutions adopted primarily apply to these two countries.

The WCPFC has a Northern Committee (WCPFC-NC), which consists of a subset of the WCPFC members and cooperating non-members, that meets annually in advance of the WCPFC meeting to discuss management of designated "northern stocks" (currently North Pacific albacore, Pacific bluefin tuna, and North Pacific swordfish). After reviewing the stock assessments prepared by the ISC, the WCPFC-NC develops the conservation and management measures for northern stocks and makes recommendations to the full Commission for the adoption of measures. Because PBF is a "northern stock" in the WCPFC Convention Area[4], without the recommendation of the Northern Committee, those measures would not be adopted by the WCPFC. The WCPFC's Scientific Committee also has a role in providing advice to the WCPFC with respect to PBF; to date its role has been largely limited to reviewing and endorsing the stock assessments prepared by the ISC.

The IATTC and WCPFC first adopted measures aimed at controlling or reducing fishing mortality of PBF in 2009 and 2012, respectively. In recent years, coordination among both RFMOs has improved in an effort to harmonize conservation and management measures to rebuild the depleted stock. All IATTC resolutions, including those on PBF, may be viewed here: http://www.iattc.org/ResolutionsENG.htm. All conservation and management measures adopted by the WCPFC may be viewed here: https://www.wcpfc.int/conservation-and-management-measures. The most relevant resolutions as they relate to recent PBF management are detailed below.

In 2012, based on the recommendations of IATTC scientific staff, the Commission adopted Resolution C-12-09 which set commercial catch limits on PBF in the EPO for the first time. This resolution limited catch by all IATTC members to 5,600 mt in 2012 and to 10,000 metric tons (mt) in 2012 and 2013 combined, notwithstanding an allowance of up to 500 mt annually for any member with a historical catch record of PBF in the eastern Pacific Ocean (i.e., the United States and Mexico). Resolution C-13-02 applied to 2014 only and, similar to C-12-09, limited catch to 5,000 mt with an allowance of up to 500 mt annually for the United States. Following the advice from the IATTC scientific staff, Resolution C-14-06 further reduced the catch limit by approximately 34% - 6,000 mt for Mexico and 600 mt for the United States for 2015 and 2016

[4] The Convention Area map https://www.wcpfc.int/convention-area-map

combined, and included provisions regarding reporting and restricting sport catches in the EPO by all CPCs. The IATTC most recently adopted Resolution C-16-08. In accordance with the recommendations of the IATTC's scientific staff, this resolution maintains the same catch limits that were applicable to 2015 and 2016 - 6,600 mt in the EPO during 2017 and 2018 combined. The final NMFS rule implementing Resolution C-16-08 was published on April 21, 2017 (82 FR 18704), with an effective date of May 22, 2017. The most recent regulations represent a ~33% reduction in comparison to the average landings from 2010-2014 (5142 mt).

The conservation and management measures adopted by the WCPFC have become increasingly restrictive since the initial 2009 measure. In 2009 total fishing effort north of 20° N was limited to the 2002-2004 annual average level. At this time, an interim management objective—to ensure that the current level of fishing mortality rate was not increased in the western Pacific Ocean—was also established. In 2010, Conservation and Management Measure (referred to as CMM) 2010-04 established catch restrictions in addition to the effort limits described above for 2011 and 2012. A similar measure, CMM 2012-06, was adopted for 2013. In 2014 (CMM 2013-09) all catch of PBF less than 30 kilograms (kg) were reduced by at least 15% of the 2002-2004 annual average. In 2015 (CMM 2014-04) this was reduced further to 50%. The CMM 2014-04 also limits all catches of PBF greater than 30 kg to no more than the 2002-2004 annual average level. The measure was amended in 2015 (CMM 2015-04) to include a requirement to adopt an "emergency rule" where additional actions would be triggered if recruitment in 2016 was extremely poor. However, this emergency rule was not agreed to at the 2016 Northern Committee annual meeting. It is expected that it will be discussed again at the 2017 meeting. Lastly, the measure was amended in 2016 (CMM 2016-04) to allow countries to transfer some of their catch limit for PBF less than 30 kg to their limit on fish larger than 30 kg (i.e., increase catch of larger fish and decrease catch of smaller fish); the reverse is not allowed. Unlike the IATTC resolutions for PBF, the current WCPFC PBF measure does not have an expiration date, although it may be amended or removed. Both the IATTC and WCPFC measures require reporting to promote compliance with the provisions of the measures.

The SRT recognized the difficulty in managing a highly migratory species that span multiple EEZs and that the challenges of this type of management have contributed to a decline in the PBF population. However, the management changes adopted in 2016 by the relevant RFMOs and participating countries have addressed the concern that PBF is being over utilized. The SRT also recognized that recommendations from IATTC and ISC to stakeholders for domestic regulatory and reporting measures have not only been adopted but also have been implemented. The increasing trend in the projected population across scenarios (see above) however, gave some confidence that the population was on a positive trajectory. Team members had a range of opinions on the effects of international management on population decline or degradation for PBF, ranging from no impact to high impact. The SRT therefore performed SEDM (Appendix II) to arrive at the conclusion that inadequacy of international management poses a low risk to population decline or degradation in PBF over the short time period (25 years), however a moderate risk over the long time period (100 years).

### 6.5.2 Domestic Management

**Magnuson-Stevens Fishery Conservation and Management Act (MSA)**

The MSA provides regional fishery management councils with authority to prepare Fishery Management Plans (FMPs) for the conservation and management of fisheries in the U.S. EEZ. The MSA was reauthorized and amended in 1996 by the Sustainable Fisheries Act (SFA) and again in 2006 by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSRA). Among other modifications, the SFA added requirements that FMPs include measures to rebuild overfished stocks. The MSRA further modified the MSA by requiring annual catch limits at a level such that overfishing does not occur and measures are in place to ensure accountability.

*U.S. West Coast* - The Pacific Fishery Management Council (Pacific Council) has purview over the U.S. West Coast fisheries, which catch the large majority of PBF caught by U.S. vessels. The Pacific Council makes recommendations on the implementation of the fishery management plan for U.S. West Coast Fisheries for highly migratory species (HMS FMP) for consideration by NMFS. Additionally, the Pacific Council makes recommendations to NMFS on issues expected to be considered by the IATTC and WCPFC. During its November 2016 meeting, the Pacific Council, in response to a separate petition that NMFS received by the Center for Biological Diversity, recommended a review of reference points for PBF at upcoming meetings. This review is ongoing as part of Amendment 4 to the HMS FMP.

The Pacific Council, in response to NMFS' 2013 determination that the PBF stock was overfished and subject to overfishing (78 FR 41033, July 9, 2013), recommended bag and possession limits for PBF in the recreational fishery. A bag limit of two fish per day and possession limit of six fish per trip were implemented in 2015 by the final rule (80 FR 44887, July 28, 2015). Based on analyses conducted at the SWFSC this was projected to reduce bags (fisherman successfully landing a PBF) by 10.4 % in U.S. waters (Stohs, 2016). In addition, the percentage overall landings reduction was projected to be 19.4% in U.S. and Mexican waters combined. Additionally, the Pacific Council provided recommendations to NMFS for trip limits to be included in the regulations implementing U.S. commercial catch restrictions in accordance with IATTC Resolution C-14-06 (80 FR 38986, July 8, 2015). Note that, based on the 2016 ISC stock assessment, the NMFS has determined that the PBF stock continues to be overfished and subject to overfishing (82 FR 07923, 19 April 2017). Because the 2016 ISC assessment did not evaluate catch data from years subsequent to 2014 when measures to reduce U.S. commercial and recreational catches of PBF became effective, NMFS did not consider the assessment to provide a scientific basis to suggest additional domestic action at this time, but encouraged the Pacific Council to work with NMFS and the Department of State to recommend actions at the international level to end overfishing and rebuild the stock.

**State of California**

NMFS coordinates closely with the California Department of Fish and Wildlife (CDFW) to monitor the PBF commercial fishery. The State of California requires that fish landed in California have a corresponding receipt, which indicates quantity landed. Together, NMFS and

CDFW monitor landings to ensure catch limits agreed to by the IATTC are not exceeded. When U.S. commercial catch limits are met, NMFS will close the fishery.

The CDFW also manages the PBF recreational fishery in California. Effective August 13, 2015, the recreational bag limit for PBF was lowered from ten to two fish per angler per day, and increased fillet-at-sea requirements were enacted.

The SRT determined that U.S. domestic management poses no or low risk to population decline or degradation in PBF. This was based largely on the small contribution of landings to the global total under past regulations and due to the fact that harvest regulations have been implemented to facilitate reduced harvest levels. The effectiveness of these new harvest regulations appears to be successful as PBF landings by CPFVs have declined since the implementation of the new regulations and appear to be unrelated to PBF availability.

## 6.6 Other Natural or Manmade Factors Affecting its Continued Existence

### 6.6.1 Climate Change

Over the next several decades climate change models predict changes to many atmospheric and oceanographic conditions. The SRT considered these predictions in light of the best available information. Unfortunately, it is challenging to separate the climate change signal from the "noise" due to the climate variability inherent in the system. Climate models suggest that the emergence of a discernable climate change signal for many variables may not occur until the mid to late $21^{st}$ century. The SRT determined that there were three physical factors resulting from climate change predictions that would have the most impact on PBF: rising sea surface temperatures (SST), increased ocean acidification, and decreases in dissolved oxygen. The SRT considered each of these factors for three broad areas which have differential effects on PBF life history: spawning grounds, foraging grounds, and transition zones (migratory pathways). The SRT also considered food web alteration due to synergistic effects of various aspects of climate change as an important consideration for PBF.

#### 6.6.1.1 Climate Change Effects on Spawning Habitat

Adult and older juvenile (>1 year) PBF are highly migratory, with a proportion of the stock moving between the eastern and western Pacific Ocean. Larger adults have also been recorded to cross the equator in the western Pacific, and occur as far south as New Zealand (Smith et al. 2010). However, spawning has only been recorded in two areas: near the Philippines and Ryukyu Islands in spring, and in the Sea of Japan during summer (Okochi et al. 2016; Shimose & Farley 2016). Environmental variability within these spawning areas has the potential to affect recruitment. As a result, climate-driven changes to conditions on spawning grounds, and subsequent effects on larval survival, may be a key vulnerability of the PBF population to climate change.

Temperature Increase

Under the most pessimistic ("business as usual") $CO_2$ emission and concentration scenarios, SSTs in the North Pacific are likely to increase substantially by the end of the 21st century (Hazen et al. 2013; Woodworth-Jefcoats et al. 2016). However, there is considerable spatial heterogeneity in these projections. The southern PBF spawning area is projected to warm ~1.5 – 2°C by the end of the 21st century, with particularly weak warming in the Kuroshio Current region. In contrast, the Sea of Japan may warm by more than 3°C compared to recent historical conditions (Seo et al. 2014; Scott et al. 2016; Woodworth-Jefcoats et al. 2016).

Spawning in PBF only occurs in comparatively warm waters, and so larvae are found within a relatively narrow temperature range (~23.5 – 29.5°C) compared to adults (Kimura et al. 2010; Tanaka & Suzuki 2016). Miyashita et al. (2000) showed that eggs hatched at between 19.9 – 31.5°C could produce normal (not deformed) larvae, but that the deformity rate was >50% in waters colder than 21.2°C, or warmer than 29.8°C. They concluded that the optimum temperature for larval development was around 25°C. Currently, SSTs within the theoretically suitable range for larvae are present near the Ryukyu Islands between April and June, and in the Sea of Japan during July and August (Caiyun & Ge 2006; Seo et al. 2014; Tanaka & Suzuki 2016). Warming of 1.5 – 3°C in the region may shift suitable times and places for spawning northwards, earlier in the year, or both.

The precise mechanisms by which warming waters will affect PBF larvae are not entirely clear. Kimura et al. (2010) assumed that the lethal temperature for larvae was 29.5°C. They based this value on temperatures where PBF larvae have been collected in the field, and on a rearing experiment where an acute increase in temperature from 26 to 29°C resulted in an increase in larval mortality (Kimura et al. 2007). Largely as a result of future water temperatures exceeding this theoretical larval survival limit, Kimura et al. (2010) suggested that PBF recruitment could decline by 36% by 2100. By this time, SSTs of >29.5°C could start to become more widespread in the region, particularly in the southern Sea of Japan during July and August. However, Muhling et al. (2010) and Tilley et al. (2016) both reported larvae of the closely-related Atlantic bluefin tuna in the Gulf of Mexico at SSTs of between 29.5 and 30.0°C. In addition, tropical tuna larvae can tolerate waters temperatures of well above 30°C (Sanchez-Velasco et al. 1999; Wexler et al. 2011; Muhling et al. 2017). PBF larvae may have fundamentally different physiology to these other species, or it is possible that the observed upper temperature limit for PBF larvae in the field is more a product of the time and place of spawning, rather than an upper physiological limit.

Older juvenile and adult PBF may have very high metabolic demands in warm water temperatures, potentially more so than their tropical congeners, and so the upper temperatures associated with larval occurrences may be determined more by adult tolerance of high temperatures than larval survival (Blank et al. 2004; Block et al. 2005; Muhling et al. 2016). ). In the GOM bluefin stay cool by remaining below the thermocline between spawning events (Teo et al 2009). Ontogenetic movement into cooler waters appears to be related to the development of endothermy, and also to the thermal inertia resulting from larger body sizes (Kitagawa et al. 2010). While small (<30cm FL) PBF juveniles are recorded in very warm waters (up to 29°C) during their first summer, larger juveniles appear to occupy somewhat cooler habitats (Bayliff

1994; Kitagawa et al. 2010; Furukawa et al. 2017). Temperature tolerances are thus likely to differ among life stages, potentially becoming cooler with age and size. However, Masuma et al. (2006, 2009) have previously observed captive adult PBF broodstock surviving and even spawning in very warm (>29°C) waters in a facility in the Amami Islands. More complete experimental determination of actual physiological temperature limits for different PBF life stages is thus required, in order for future climate change impacts to be assessed. In addition, the potential for transgenerational adaptation is unknown for species such as PBF. While recent research suggests that significant adaptation to warming temperatures is possible in smaller, coral-reef associated fish species (Donelson et al. 2016; Rummer & Munday 2017), the applicability of these results to large, highly migratory tunas is unclear.

Larval Growth and Feeding

As well as directly affecting hatch success and survival, warming temperatures may increase larval growth rates. Faster growth with warmer temperatures has been demonstrated in cultured larvae of PBF and other tunas (Kimura et al. 2010; Wexler et al. 2011). Satoh et al. (2013) also found a positive effect of both temperature and food availability on larval PBF growth in the field. Faster-growing larvae may be more likely to survive to the juvenile stage, due to less time spent in the predation-vulnerable larval stages (Tanaka et al. 2006). However, to sustain rapid growth, sufficient food resources are required. Larvae appear to have a low tolerance to starvation, so the abundance of suitable prey is likely to be even more important for survival at increased temperatures (Tanaka et al. 2008).

Similar to other tuna species, larval PBF appear to have highly specialized and selective diets (Uotani et al. 1990; Llopiz & Hobday 2015). Smaller larvae rely primarily on copepod nauplii, before moving to cladocerans, copepods such as *Farranula* and *Corycaeus* spp. and other zooplankton. In the Sea of Japan region, the occurrence of potentially favorable prey organisms for larval PBF appears to be associated with stable post-bloom conditions during summer (Chiba & Saino, 2003). This suggests a potential phenological match to PBF spawning. Environmentally-driven changes in the evolution of this zooplankton community, or the timing of spawning, could thus affect the temporal match between larvae and their prey. Woodworth-Jefcoats et al. (2016) project a ~10 – 20% decrease in overall zooplankton density in the western Pacific Ocean, but how this may relate to larval PBF prey fields is not yet known.

Larval Transport

Mechanisms for delivery of pelagic post-larvae to juvenile nursery areas around coastal Japan are different between the two spawning areas. Larvae spawned into the Sea of Japan appear to be retained locally, and recruit to nearby coastal habitats. In contrast, larvae spawned near the Ryukyu Islands region are advected northwards via the Kuroshio Current, arriving near coastal nursery areas after several weeks. Kitagawa et al. (2010) showed that under current conditions, larvae spawned on the southern spawning ground can be delivered to nursery areas at favorable times, and into favorable temperatures for juveniles. However, if spawning times and areas shift in response to climate change, this oceanographic link may become less effective. For example, as temperatures warm, locations of favorable spawning habitat may move further north (Kimura et al. 2010). In addition, several studies project a future strengthening of the Kuroshio Current (e.g. Sakamoto et al. 2005; Xiaolin et al. 2012). Both of these factors would shorten the journey between spawning grounds and juvenile habitats, and potentially result in insufficient time for larvae to develop. Adults may be able to adapt by spawning earlier in the year. However, if adults are not located in spawning areas year-round, environmental cues which initiate migration from distant feeding areas may be insufficiently correlated with conditions on spawning grounds to allow effective adaptation (Edwards & Richardson, 2004; Anderson et al., 2013). Despite this, the previous observation of spawning between May and November in captive adults suggests that some plasticity in spawning behavior is possible (Masuma 2009).

Ocean Acidification and Dissolved Oxygen

As $CO_2$ uptake by the oceans increases, ocean pH will continue to decrease (Feely et al. 2009), with declines of between ~0.2 and 0.4 expected in the western North Pacific by 2100 under Representative Concentration Pathway (RCP) 8.5 (Ciais et al. 2013). RCP 8.5 is a high emission scenario, which assumes that radiative forcing due to greenhouse gas emission will continue to increase strongly throughout the 21st century (Riahi et al. 2011). Rearing experiments on larval yellowfin tuna suggest that ocean acidification may result in longer hatch times, sub-lethal organ damage, and decreased growth and survival (Bromhead et al. 2014; Frommel et al. 2016). Other studies on coral reef fish larvae show that acidification can impair sensory abilities of larvae, and in combination with warming temperatures, can negatively affect metabolic scope (Munday et al. 2009a,b; Dixson et al. 2010; Simpson et al. 2011). Surface ocean pH on PBF spawning grounds is currently higher than that in the broader North Pacific (~8.1 – 8.2) (Feely et al. 2009). How this may affect the ability of PBF larvae (in particular) to adapt to ocean acidification is unknown. Recent studies have shown that future adaptation to rising $CO_2$ and acidification could be facilitated by individual genetic variability (Schunter et al. 2017). In addition, transgenerational plasticity may allow surprisingly rapid adaptation across generations (Rummer & Munday 2017). However, these studies examined small coral reef fish species, so results may not transfer to larger, highly migratory species such as PBF. As well as incurring direct effects on PBF, ocean acidification is also likely to change the prey base available to all life stages of this species. Different organisms vary substantially in their sensitivity to the combined effects of acidification and warming (Byrne 2011). A shift in the prey assemblage towards organisms more tolerant to acidification is therefore likely in the future.

Current projections estimate a future decline in dissolved oxygen of ~3 – 6% by 2100 under RCP 8.5 (Bindoff et al. 2013; Ciais et al. 2013). This may be most relevant for spawning-sized adult PBF, which may be subject to greater metabolic stress on spawning grounds. While some studies exist on the effects of temperature on metabolic rates, cardiac function and specific dynamic action in juvenile PBF (e.g. Blank et al. 2004; 2007; Clark et al. 2008; 2010; 2013; Whitlock et al. 2015), there are no published studies on larger adults, or on larvae. While future warming and decreases in dissolved oxygen may reduce the suitability of some parts of the PBF range (e.g. Muhling et al. 2016), likely biological responses to this are not yet known.

#### 6.6.1.2 Climate Change Effects on Foraging Grounds and Alterations to Food Webs

Adult and older juvenile (>1 year) PBF disperse from the spawning grounds in the western Pacific and older juvenile can make extensive migrations, utilizing much of the temperate North Pacific. An unknown proportion of 1-2 year old fish migrate to foraging grounds in the eastern North Pacific (California Current LME) and typically remain and forage in this region for several years (Bayliff et al. 1991; Bayliff 1994; Rooker et al. 2001; Kitagawa et al. 2007; Boustany et al. 2010; Block et al. 2011; Madigan et al. 2013; Whitlock et al. 2015). Climate-driven changes in this foraging region could impact the thermal and biogeochemical habitat as well as the abundance, distribution and quality of key prey species.

Temperature Increase

Under RCP 8.5, SSTs in the California Current are expected to increase up to ~1.5-2°C by the end of the 21st century (Hazen et al. 2013; Woodworth-Jefcoats et al. 2016). This is a smaller warming signal than that anticipated for some portions of the western Pacific spawning grounds, but substantial nonetheless.

PBF tagged in the California Current demonstrate a seasonal north-south migration between Baja California and northern California (42°N) (Boustany et al. 2010; Block et al. 2011; Whitlock et al. 2015), although some fish travel as far north as Washington State. The seasonal migration follows local peaks in productivity (as measured by surface chlorophyll), such that fish move northward from Baja California after the local productivity peak in late spring to summer (Boustany et al. 2010; Block et al. 2011). While the median SST for archivally tagged PBF in the California Current was 17°C (Perle 2011), SST from catch and electronic tag data provide an overall range of ~12 °C to ~23 °C. Uniform warming in this region could impact PBF distribution by moving their optimal temperature range (and thermal tolerance) northward. However, it is unlikely that rising temperatures will be a limiting factor for PBF, as appropriate thermal habitat will likely remain available. Their distribution and migration may be more influenced by changes in prey availability and quality, driven by changes in upwelling and resultant productivity.

Coastal Upwelling

The high productivity and biodiversity of the California Current is driven largely by seasonal coastal upwelling. Although there is considerable uncertainty on how climate change will impact coastal upwelling, basic principles indicate a potential for upwelling intensification (Bakun 1990). Bakun's hypothesis suggested that the rate of heating over land would be enhanced relative to that over the ocean, resulting in a stronger cross-shore pressure gradient and a proportional increase in alongshore winds and resultant upwelling (Bakun et al. 2015; Bograd et al. 2017). A recent publication (Sydeman et al. 2014) described a meta-analysis of historical studies on the Bakun hypothesis and found general support for upwelling intensification, but with significant spatial (latitudinal) and temporal (intraseasonal) variability between and within the eastern boundary current systems. In the California Current, a majority of analyses were indicative of increased upwelling intensity during the summer (peak) months, though this signal was most pronounced in the northern California Current (Sydeman et al. 2014).

To date, global climate models have generally been too coarse to adequately resolve coastal upwelling processes (Stock et al. 2010), although recent studies analyzing ensemble model output have found general support for projected increases in coastal upwelling in the northern portions of the eastern boundary current systems (Wang et al. 2015; Rykaczewski et al. 2015). Using an ensemble of more than 20 global climate models from the Intergovernmental Panel on Climate Change's Fifth Assessment Report), Rykaczewski et al. (2015) found evidence of a small projected increase in upwelling intensity north of ~40°N in the California Current by the end of the 21st century under RCP 8.5, and a more robust decrease in upwelling intensity south of 40°N, the region typically inhabited by PBF. Perhaps more importantly, Rykaczewski et al. (2015) described projected changes in the phenology of coastal upwelling, with an earlier transition to positive upwelling within the peak upwelling domain. Overall, these results suggest a poleward displacement of peak upwelling and potential lengthening of the upwelling season in the California Current, even if upwelling intensity may decrease. The phenological changes in coastal upwelling may be most important, as these may lead to spatial and temporal mismatches between PBF and their preferred prey (Cushing 1990; Edwards and Richardson 2004; Bakun et al. 2015). However, their highly migratory nature and plasticity in migratory patterns may help to mitigate shifts in phenology.

Upper ocean warming is likely to enhance water column stratification, producing a stronger thermocline and rendering upwelling less effective in delivering inorganic nutrients to the euphotic zone, thus reducing lower trophic productivity (Palacios et al. 2004; Bakun et al. 2015). The relative contribution of varying wind forcing (Rykaczewski et al. 2015) and water column stratification (Palacios et al. 2004; Palacios et al. 2013) on nutrient supply to the euphotic zone is uncertain, and will likely be highly variable in space and time (Jacox et al. 2015). Exact changes to the California Current in association with climate change are impossible to predict.

<u>Source Waters to the California Current</u>

The characteristics of the water masses that are transported into the California Current, and that ultimately feed the supply of upwelled waters, will also likely have important ecosystem effects (Bakun et al. 2015; Bograd et al. 2017). Using a global climate model, Rykaczewski and Dunne (2010) described projected increases in the nitrate supply and lower trophic productivity in the California Current in the 21st century, which they attributed to the nutrient enrichment of deep source waters resulting from decreased ventilation in the North Pacific. Although these secular biogeochemical trends are not projected to be discernable until the middle of the century, observations from the long-term CalCOFI program have shown substantial trends in both dissolved oxygen (decreasing) and inorganic nutrient content (generally increasing) in thermocline waters of the southern California Current (Meinvielle and Johnson 2013; Bograd et al. 2015). These changes have been shown to impact the distribution and abundance of pelagic fish (Koslow et al., 2011). Given that these depths supply coastal upwelling (Chhak and Di Lorenzo 2007), these source water changes could drive substantial changes in the ecosystem, including a compression of viable habitat for many species, habitat shifts, and broad changes in community structure (Koslow et al., 2011; Bograd et al., 2015; Bograd et al. 2017), thus impacting the distribution and type of prey available to PBF.

Ocean Acidification and Dissolved Oxygen

Another factor to include in considerations of climate change impacts is biogeochemical changes. Driven by upper ocean warming, changes in source waters, enhanced stratification and reduced mixing, the dissolved oxygen content of mid-depth oceanic waters is expected to decline (Keeling et al. 2010). This effect is especially important in the eastern Pacific, where the Oxygen Minimum Zone (OMZ) shoals to depths well within the vertical habitat of PBF and other highly migratory species and, in particular, their prey (Stramma et al. 2010; Moffit et al. 2015). The observed trend of declining oxygen levels in the Southern California Bight (Bograd et al. 2008; McClatchie et al. 2010; Bograd et al. 2015), combined with an increase in the frequency and severity of hypoxic events along the U.S. West Coast (Chan et al. 2008; Keller et al. 2010; Booth et al. 2012), suggests that declining oxygen content could drive ecosystem change. Specifically, the vertical compression of viable habitat for some benthic and pelagic species could alter the available prey base for PBF. The effect of a shoaling oxygen minimum zone may be positive as prey are compressed into a narrower layer as has been documented in tropical waters by Prince and Goodyear (2006). To the extent that PBF are opportunistic feeders, they could have resilience to these climate-driven changes in their prey base.

The effects of increasing hypoxia on marine fauna in the California Current may be magnified by ocean acidification. Ekstrom et al. (2015) predicted the West Coast is highly vulnerable to ecological impacts of ocean acidification due to reduction in aragonite saturation state exacerbated by coastal upwelling of "corrosive", lower pH waters (Feely et al. 2008). The most acute impacts would be on calcifying organisms (some marine invertebrates and pteropods), which are not generally part of the adult PBF diet. While direct impacts of ocean acidification on PBF may be minimal within their eastern Pacific foraging grounds, some common PBF prey do rely on calcifying organisms (Fabry et al. 2008).

Alterations to Food Web

The information directly relating to food web alterations that may impact PBF is scarce. While changes to upwelling dynamics in foraging areas has been examined, it is still relatively speculative, and literature on the potential impacts of the projected changes is limited. Given their trophic position as a top predator, and that PBF are opportunistic feeders that can change their preferred diet from year to year, alterations to the food web may have less impact on PBF than on other organisms that are reliant on specific food sources.

#### 6.6.1.3 Climate Change Effects on Migratory Pathways

PBF undergo trans-Pacific migrations, in both directions, between the western Pacific spawning grounds and eastern Pacific foraging grounds (Boustany et al. 2010; Block et al. 2011). For both migrations, PBF remain within a relatively narrow latitudinal band (30-40°N) within the North Pacific Transition Zone (NPTZ), which is characterized by generally temperate conditions. This region, marking the boundary between the oligotrophic subtropical and more productive subarctic gyres, is demarcated by the seasonally-migrating Transition Zone Chlorophyll Front (TZCF; Polovina et al. 2001; Bograd et al. 2004). The TZCF has been identified as an important migratory and foraging habitat for a number of apex predators, including PBF (Polovina et al. 2000; 2001). Climate-driven changes in the position of the TZCF, and in the thermal environment and productivity within this region, could impact the migratory phase of the PBF life cycle.

Temperature Increase

Under RCP 8.5, SSTs in the NPTZ are expected to increase by ~2-3°C by the end of the 21st century (Woodworth-Jefcoats et al. 2016), with the highest increases on the western side. At deeper levels (~200 m), some of the strongest projected warming is within the NPTZ, implying a large increase in overall heat content in this region. Thus, maintenance of thermal preferences may require PBF to take a more northerly route during their trans-Pacific migrations.

Transition Zone Displacement and Reduced Productivity

The increased temperatures within the NPTZ are part of the broader projected changes in the central North Pacific Ocean, including an expansion of the oligotrophic Subtropical Gyre, a northward displacement of the transition zone, and an overall decline in productivity (Polovina et al. 2011). The impacts of these changes on species that make extensive use of the NPTZ could be substantial, resulting in a gain or loss of core habitat, distributional shifts, and regional changes in biodiversity (Hazen et al. 2013). Using habitat models based on a multi-species biologging dataset, and a global climate model run under "business-as-usual" forcing (the A2 $CO_2$ emission scenario from the IPCC's fourth assessment report), Hazen et al. (2013) found a substantial loss of core habitat for a number of highly migratory species, and small gains in viable habitat for other species, including PBF. Although the net change in total potential PBF core habitat did not decrease, the projected physical changes could negatively impact them. The northward displacement of the NPTZ, and TZCF, could lead to longer migrations requiring greater energy expenditure. The generally lower productivity of the region could also diminish the abundance or quality of the PBF prey base.

A recent study of projected climate change in the North Pacific that used an ensemble of 11 climate models, including measures of primary and secondary production, found that increasing temperatures could alter the spatial distribution of tuna and billfish species across the North Pacific (Woodworth-Jefcoats et al. 2016). As with Hazen et al. (2013), this study found species richness increasing to the north following the northward displacement of the NPTZ. They also estimated a 2-5% per decade decline in overall carrying capacity for commercially important tuna and billfish species, driven by warming waters and a basin-scale decline in zooplankton densities (Woodworth-Jefcoats et al. 2016). While there is still substantial uncertainty inherent in these climate models, we can say with some confidence that the central North Pacific, which encompasses a key conduit between PBF spawning and foraging habitat, is likely to become warmer and less productive through the 21st century**.**

#### 6.6.1.4 Climate Change Conclusions

The SRT considered the best available evidence in its evaluation of the impacts of climate change to PBF extinction. Three physical factors resulting from climate change predictions emerged that would have the most impact on PBF: SST, increased ocean acidification, and decreases in dissolved oxygen. The impact of these changes, and others, on the forage base were also considered.

After careful consideration and dialogue, the SRT concluded that ocean acidification, food-web alterations and changes in dissolved oxygen content due to climate change would have no to low risk to population decline or degradation in PBF on the short time scale (25 years), and low to moderate risk on the long time scale (100 years). The reasoning behind this decision for acidification centered primarily on the disconnect between PBF and the lower trophic level prey which would be directly affected by acidification as well as by the lack of information on direct impacts on acidification on pelagic fish.  For food-web alterations, the opportunistic feeding strategy and highly migratory nature of PBF was considered to reduce the associated threat due to a shift in the prey base.  Rising SSTs due to climate change required SEDM as the range of values assigned by each team member was large.  Following the SEDM, the SRT concluded that SST rise poses a low risk to population decline or degradation in PBF over the short (25 year) and long (100 year) time frames.  This decision was reached primarily due to the highly migratory nature of PBF, despite likely latitudinal shifts in preferred habitat it would take little effort for PBF to shift their movements along with the changing conditions. However, the SRT noted the high level of uncertainty regarding the effects of warming temperatures (and other climate change impacts) across different life stages of PBF.

### 6.6.2 Fukushima Associated Radiation

On 11 March, 2011, the Tōhoku megathrust earthquake at magnitude 9.1 produced a devastating tsunami that hit the Pacific coast of Japan. As a result of the earthquake, the Fukushima Daiichi Nuclear Power Plant was compromised, releasing radionuclides directly into the adjacent sea. The result was a one to two week pulse of emissions of the cesium radioisotopes $^{134}$Cs and $^{137}$Cs. These isotopes were biochemically available to organisms in direct contact with the contaminated water (Oozeki et al., 2017).

Madigan et al. (2012) reported on the presence of $^{134}$Cs and $^{137}$Cs in PBF caught in California in ratios that strongly suggested uptake as a result of the Fukushima Daiichi accident. The results indicated that highly migratory species can be vectors for the trans-Pacific movement of radionuclides. Importantly, the study highlighted that while the radiocesium present in the PBF analyzed was directly traceable to the Fukushima accident, the concentrations were 30 times lower than background levels of naturally occurring radioisotopes such as potassium-40 ($^{40}$K). In addition, Madigan et al. (2012) estimated the dose to human consumers of fish from Fukushima derived $^{137}$Cs was at 0.5% of the dose from Polonium-210 ($^{210}$Po), a natural decay product of Uranium-238 ($^{238}$U), which is ubiquitously present and to which humans are exposed regularly on a global scale.

Fisher et al. (2013) further evaluated the dosage and associated risks to marine organisms and humans (by consumption of contaminated seafood) of the cesium radioisotopes associated with the Fukushima Daiichi accident. They confirmed that dosage of radioisotopes from consuming seafood were dominated by naturally occurring radionuclides and that those stemming directly from Fukushima derived radiocesium were three to four orders of magnitude below doses from these natural radionuclides. Doses to marine organisms were two orders of magnitude lower than the lowest benchmark protection level for ecosystem health (ICRP 2008). The study concluded that even on the date at which the highest exposure levels may have been reached, dosages were very unlikely to have exceeded reference levels. This indicates that the amount of Fukushima derived radionuclides is not cause for concern with regard to the potential harm to the organisms themselves.

The SRT was unanimous in considering Fukushima associated radiation as contributing no risk to population decline or degradation in PBF. This was based largely on the absence of empirical evidence showing negative effects of Fukushima derived radiation on PBF.

## 6.7 Small Population Concerns

If a population is very small relative to historical abundance, there are a number of inherent risks that may increase the potential for the population to decline further and be at an increased risk of extinction. These risks are tied to survival and reproduction (e.g. Allee or other depensation effects) via three mechanisms: ecological (e.g. mate limitation, cooperative defense, cooperative feeding, and environmental conditioning), genetic (e.g. inbreeding and genetic drift), and demographic stochasticity (i.e. individual variability in survival and recruitment) (Berec et al. 2007). The actual number at which populations would be considered critically low and at risk varies depending on the species and the risk being considered. While the PBF population is estimated to contain >1.6 million individuals, of which >140,000 are reproductively capable, the SRT deemed it prudent to examine the factors above that are traditionally used to evaluate the impacts of relatively low population numbers.

### 6.7.1 Reproduction

If a population is critically small in size, individuals may have difficulty finding a mate. However, for fish species that spawn in geographically explicit areas, the probability of finding a mate depends largely on density on the spawning grounds rather than on absolute abundance. Pacific bluefin tuna are a schooling species and individual PBF are not randomly distributed throughout their range. They also exhibit regular seasonal migration patterns which include aggregating at two separate spawning grounds with particular oceanographic characteristics (Kitigawa et al. 2010). This schooling and aggregation behavior serves to increase their local density and the probability of individuals finding a mate. This mating strategy could reduce the effects of small population size on finding mates over other strategies that do not concentrate individuals. It is unknown whether spawning behavior is triggered by environmental conditions or densities of individuals. If density of adults triggers spawning, then reproduction could be affected by high levels of depletion. However, no evidence exists to support this hypothesis.

### 6.7.2 Demographic Stochasticity

If a population is critically small in size, chance variations (e.g., the difference between the predicted and the actual values) of recruitment or mortality across age classes can put the population at added risk of extinction. Demographic stochasticity refers to the variability of annual population change arising from random birth and death events at the individual level. When populations are very small (e.g., < 100 individuals), chance demographic events can have a large impact on the population. Species with low mean annual survival rates are generally at greater population risk from demographic stochasticity than those that are long-lived and have high mean annual survival rates. In other words, species that are long-lived and have high annual survival rates have lower "safe" abundance thresholds, above which the risk of extinction due to chance demographic processes becomes negligible. Even though the percentage of adult PBF relative to historical levels is low, they still number in the hundreds of thousands. In addition, the total population size in 2014 as estimated by the 2016 ISC stock assessment was 1,625,837. The high number of individuals, both mature and immature, should therefore counteract a particular year with low survivorship or recruitment

### 6.7.3 Genetics

If a population is critically small in size, Allee effects can act upon genetic diversity to reduce the prevalence of beneficial alleles through genetic drift. This may lower the population's fitness by reducing adaptive potential and increasing the accumulation of deleterious alleles due to increased levels of inbreeding. Population genetic theory typically sets a threshold of 50 individuals (i.e. 25 males, 25 females) below which irreversible loss of genetic diversity is likely to occur in the near future. This value, however, is not necessarily based upon the number of individuals present in the population (i.e., census population size, $N_C$) but rather on the effective population size ($N_E$), which is linked to the overall genetic diversity in the population and is typically less than $N_C$. In extreme cases $N_E$ may be much (e.g. 10 – 10,000 times) smaller, typically for species that experience high variance in reproductive success (e.g., sweepstakes recruitment events). $N_E$ may also be reduced in populations that deviate from a 1:1 sex ratio and from species that have suffered a genetic bottleneck.

With respect to considerations of $N_E$ in PBF, the following points are relevant. Both nuclear and mitochondrial DNA support a highly diverse population (Qiu and Miyamoto, 2011; Tseng, et al., 2014). With two separate spawning grounds, and adult numbers remaining in the hundreds of thousands, genetic diversity is expected to still be at high levels with little chance for inbreeding given that billions of gametes combine in concentrated spawning events.

### 6.7.4 Stochastic and Catastrophic Events

Animals that are highly mobile with a large range are less susceptible to stochastic and catastrophic events (such as oil spills) than those that occur in concentrated areas across life history stages. PBF are likely to be resilient to catastrophic and stochastic events for the following reasons: 1) they are highly migratory, 2) there is a large degree of spatial separation between life history stages, 3) there are two separated spawning areas, and 4) adults reproduce over many years such that poor recruitment even over a series of years will not result in reproductive collapse. As long as this spatial arrangement persists and poor recruitment years do not exceed the reproductive age span for the species, PBF should be resilient to both stochastic and catastrophic events.

### 6.7.5 Allee Effects

Although PBF are resilient to many of the risks that small populations face, there is increasing evidence for a reduction in population growth rate for marine fishes that have been fished to densities below those expected from natural fluctuations (Hutchings 2000 2001). These studies focus on failure to recover at expected rates but not necessarily on probability of extinction. A far more serious issue is not just reducing population growth but reduction to the point that populations decrease (death rates exceed recruitment). Unfortunately, the reviews of marine fish stocks do not make a distinction between these two important categories of depensation: reduced but neutral or positive growth versus negative growth. Many of the cases reviewed suggested that depensatory effects for populations reduced to relatively low levels (0.2 to 0.5 $SSB_{msy}$) would increase time to recovery, but no mention was made of declining towards extinction. However, these cases did not represent the extent of reduction observed in PBF (0.14 $SSB_{msy}$). Thus, this case falls below that where recovery has been observed in other marine fishes and thus there remains considerable uncertainty as to how the species will respond to reductions in fishing pressure. However, the ISC stock projections show an increasing or stable SSB under all scenarios evaluated for PBF even in the absence of the increased harvest reductions that have been implemented. This provides some measure of support for the hypothesis that the PBF population had yet to reach such low population numbers that negative population growth due to Allee effects in the terminal year of the ISC model (2014).

Hutchings *et al.* 2012 also show that there is no positive relationship between per capita population growth rate and fecundity in a review of 233 populations of teleosts. Thus, the prior notion that high fecundity provides more resilience to population reduction and ability to quickly recover may not be robust. These findings, although not providing examples that marine fishes exploited to low levels will decline towards extinction, suggest that at a minimum such populations may not recover quickly. However, PBF recently showed an instance of positive growth from population levels similar to the 2014 end year used in the most recent stock assessment. While it is unclear what conditions are needed to allow positive growth for populations at low numbers, the available data for PBF suggests potential for recovery at low population levels.

The SRT determined that small population concerns posed low risk to population decline or degradation in PBF over both the 25 and 100 year time scales although with low certainty. This was largely due to the estimated population size of >1.6 million individuals, of which >140,000 are reproductively capable, which, coupled with previous evidence of recovery from similarly low numbers and newly implemented harvest regulations, strongly suggests that small population concerns are not particularly severe in PBF.

# 7.0 EXTINCTION RISK ANALYSIS

## 7.1 Overall Section 4(a)(1) Category and Small Population Concerns Analysis

The SRT conducted an extinction risk analysis to summarize the risk of extinction to PBF by threats in each of the ESA section 4(a)(1) categories, as well as for an additional category that the SRT regarded as necessary to evaluate (small population concerns; see section 6.7). This risk analysis does not represent a decision by the SRT on whether the species should be or should not be listed under the ESA. The goal of the section 4(a)(1) category analysis was to ascertain which, if any, of these broad categories posed a particularly high risk of extinction to PBF. Individual threats within each of the section 4(a)(1) categories have been reviewed in the sections above.

The SRT utilized SEDM to assess the degree of risk posed by the section 4(a)(1) categories and small population concerns. After considering scores for each specific threat within a particular category, team members were asked to distribute 100 plausibility points across a range of severity and confidence categories as described below. This analysis was done over a short (25 year) and long (100 year) time scale.

Within each threat category, individual threats have not only different magnitudes of influence on the overall risk to the species (weights) but also different degrees of certainty. The overall threat within a category is cumulative across these individual threats. Thus, the overall threat is no less than that for the individual threat with the highest influence but may be greater as the threats are taken together. For example, many individual threats rated as moderate (2) may result in an overall threat for that category of at least moderate but potentially high. When evaluating the overall threat, individual team members consider all threats taken together and performed a mental calculation weighting the threats according to their expertise using the definitions below.

The level of confidence asks the team member to record their confidence in their overall scoring for that category. If, for example, the scoring for the overall threat confidence was primarily a function of a single threat and that threat had a high level of certainty in the Threat table, then they would likely have a high level of confidence in the overall confidence score. Alternatively, the overall confidence score could be reduced due to a combination of threats some of which the team member had a low level of certainty about and consequently communicates this lower overall level of confidence with a corresponding score (using the definitions below). Generally, the level of confidence will be most influenced by the level of certainty in the threats of highest severity. The level of confidence for threats with no to low severity within a category that contains moderate to high severity threats will not be important to the overall level of confidence.

Levels of severity and confidence are defined as follows.

**Level of Severity:** The level of risk that this threat category is likely to contribute to the decline or degradation of the PBF population over each time frame (over the next 25 years or over the next 100 years). Specific rankings for severity are defined as follows:

- **3** = **High:** The threat category is likely to *eliminate or seriously degrade* the PBF population.
- **2 = Moderate:** The threat category is likely to *moderately degrade* the PBF population.
- **1 = Low:** The threat category is likely to *only slightly impair* the PBF population.
- **0 = None:** The threat category is *not likely to impact* the PBF population.

**Level of Confidence:** The level of confidence that the threat category is affecting, or is likely to affect, PBF populations over the time frame considered. Specific rankings for confidence are defined as follows:

- **3 = High:** There is a *high degree of confidence* to support the conclusion that this threat category is affecting, or is likely to affect, the PBF population with the severity ascribed over the time frame considered.
- **2 = Moderate:** There is a *moderate degree of confidence* to support the conclusion that this threat category is affecting, or is likely to affect, the PBF population with the severity ascribed over the time frame considered.
- **1 = Low:** There is a *low degree of confidence* to support the conclusion that this threat category is affecting, or is likely to affect, the PBF population with the severity ascribed over the time frame considered.
- **0 = None:** There is *no confidence* to support the conclusion that this threat category is affecting, or is likely to affect, the PBF population with the severity ascribed over the time frame considered.

Appendix I a-b show the full SEDM tables for all SRT members. Tables 3-4 below shows a summary of overall SEDM analysis for each section 4(a)(1) category with the category with the largest number of likelihood points (shortened in the table to "Score") highlighted in grey. The Scores sum to 100 and represent the sum of the members scores divided by the number of members.

**Table 3. Mean Scores and standard deviations for section 4(a)(1) categories and small population concerns over the 25 year time frame.**

| ESA Section 4(a)(1) Category (25 years) | | Severity | | | | Certainty | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Overutilization | Mean Score | 1.4 | 22.1 | 63.6 | 12.9 | 1.4 | 30.0 | 51.4 | 17.1 |
| | StDev | 3.8 | 17.8 | 13.8 | 12.2 | 3.8 | 26.5 | 27.3 | 29.3 |
| Habitat destruction, modification or curtailment | Mean Score | 52.9 | 37.9 | 6.4 | 2.9 | 14.3 | 30.7 | 52.1 | 2.9 |
| | StDev | 36.5 | 25.1 | 9.4 | 4.9 | 19.0 | 21.7 | 31.3 | 4.9 |
| Disease or Predation | Mean Score | 65.0 | 28.6 | 6.4 | 0.0 | 21.4 | 32.1 | 41.4 | 5.0 |
| | StDev | 29.9 | 24.1 | 7.5 | 0.0 | 25.4 | 27.7 | 35.2 | 9.6 |
| Inadequacy of existing regulatory mechanisms | Mean Score | 23.6 | 43.6 | 27.1 | 5.7 | 1.4 | 35.7 | 40.7 | 22.1 |
| | StDev | 31.2 | 26.9 | 30.9 | 11.3 | 3.8 | 33.1 | 25.6 | 27.4 |
| Other natural or manmade factors | Mean Score | 22.9 | 60.0 | 12.9 | 4.3 | 1.4 | 38.6 | 49.3 | 10.7 |
| | StDev | 18.7 | 14.1 | 12.2 | 7.9 | 3.8 | 28.4 | 25.4 | 11.7 |
| Small population concerns | Mean Score | 32.9 | 45.7 | 17.1 | 4.3 | 19.3 | 60.7 | 17.9 | 2.1 |
| | StDev | 26.9 | 21.7 | 24.1 | 5.3 | 20.9 | 14.8 | 13.8 | 5.7 |

**Table 4. Mean Scores and standard deviations for section 4(a)(1) categories and small population concerns over the 100 year time frame.**

| ESA Section 4(a)(1) Category (100 years) | | Severity | | | | Certainty | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Overutilization | Mean Score | 2.9 | 20.7 | 61.4 | 15.0 | 17.9 | 42.1 | 30.0 | 10.0 |
| | StDev | 7.6 | 17.4 | 13.1 | 11.9 | 18.2 | 21.6 | 21.6 | 19.1 |
| Habitat destruction, modification or curtailment | Mean Score | 40.7 | 39.3 | 15.0 | 5.0 | 15.7 | 44.3 | 35.7 | 4.3 |
| | StDev | 31.1 | 17.9 | 18.9 | 8.7 | 21.5 | 23.5 | 27.1 | 7.9 |
| Disease or Predation | Mean Score | 49.3 | 43.6 | 7.1 | 1.4 | 27.1 | 36.4 | 31.4 | 5.0 |
| | StDev | 32.5 | 30.1 | 7.6 | 3.8 | 27.5 | 27.5 | 36.4 | 9.6 |
| Inadequacy of existing regulatory mechanisms | Mean Score | 22.1 | 38.6 | 32.1 | 7.1 | 9.3 | 40.7 | 38.6 | 11.4 |
| | StDev | 25.5 | 21.9 | 28.1 | 11.1 | 18.4 | 33.3 | 30.4 | 10.3 |
| Other natural or manmade factors | Mean Score | 6.4 | 42.9 | 43.6 | 7.1 | 7.1 | 40.7 | 42.1 | 10.0 |
| | StDev | 7.5 | 22.9 | 18.4 | 9.1 | 11.1 | 20.1 | 19.5 | 11.5 |
| Small population concerns | Mean Score | 31.4 | 45.0 | 17.1 | 6.4 | 20.0 | 60.0 | 15.7 | 4.3 |
| | StDev | 24.1 | 19.1 | 23.2 | 8.5 | 20.8 | 12.6 | 15.9 | 7.9 |

Based on the SEDM analysis, the SRT concluded that overutilization, particularly by commercial fishing activities, had the greatest potential influence on population decline or degradation in PBF and poses a moderate risk to decline or degradation of the population over both the 25 and 100 year time scales. While the degree of certainty for this risk was moderate for the 25 year time frame, it was low for the 100 year time frame. This largely reflects the inability to accurately predict trends in both population size and catch over the longer time frame. In addition, management regimes may shift in either direction in response to the population trends at the time. Of particular concern was the increased landings over the last two decades of age-0 PBF. Management schemes have been adopted to decrease landings of smaller fish and the SRT views this as a positive step.

Over the short and long time frames, the SRT determined that habitat destruction, disease, and predation are not likely to degrade or cause decline in the PBF population. The confidence for this conclusion was moderate for the short time frame and low for the long time frame. Among the specific threats in the Habitat Destruction category, water pollution was ranked the highest (mean severity score 1.5). This was largely due to the fact that any degradation to PBF by water pollution is a passive event. That is, behavioral avoidance might not be possible, whereas other specific threats involved factors where active avoidance would be possible.

Based on the SEDM analysis, the SRT concluded that inadequacy of existing regulatory mechanisms posed a low risk to population decline or degradation in PBF over both the 25 and 100 year time scales given the stable or upward trends of future projected SSB over the short time scale from various harvest scenarios in the 2016 ISC stock assessment. These current harvest levels were adjusted by the relevant RFMOs to reduce catches in an effort to rebuild the stock following the 2016 stock assessment. The confidence levels were moderate for the 25 year time frame and low for the 100 year time frame.

While any international agreement has implicit uncertainty in compliance, most of the SRT members considered that the changes to management implemented by the RFMO's in the Pacific in response to the 2016 stock assessment recommendations will aid in reducing landings and rebuilding the PBF population. One member of the SRT, however, expressed concern that because RFMOs lack enforcement abilities, there is no certainty that individual countries will abide by the recommendations. That member suggested that evidence is needed to show that new management recommendations are effective given that in their experience international management has been shown to be problematic, especially when there are no actual regulatory consequences imposed if individual countries do not follow voluntary management advice.

Other natural or manmade factors which included climate change were scored as having low risk to population decline or degradation in PBF over the 25 year time frame and moderate risk over the 100 year time frame with a moderate level of confidence for both.

Small population concerns were rated as having a low level of risk to population decline or degradation in PBF over the two time scales but with low confidence for each. Although most members of the SRT agreed that having a mature PBF population in excess of 140,000 was a sufficient buffer against small population concerns, it was noted by one member that the response of a species to being at less than 5% of the theoretical, model-derived unfished number of mature individuals was of concern given the lack of understanding of whether density serves as a trigger to spawning behavior  Other members concluded that the fact that the population had previously increased after being at similarly low levels was an indicator of the potential for recovery.

### 7.2 Overall PBF Extinction Risk Analysis

The SRT conducted an overall extinction risk analysis to summarize the risk of extinction to PBF. This risk analysis does not represent a decision by the SRT on whether the species should be or should not be listed under the ESA.  The SRT utilized SEDM in assessing the severity of risk to extinction of PBF posed by all factors considered in the status report.  Assessment of risk included a broad range of factors including the all ESA section 4(a)(1) categories, small population concerns, the results from the recent stock assessment, PBF life history parameters and strategy, and historic trends. After considering all factors herein, team members were asked to distribute 100 plausibility points across a range of severity for each of three risk categories as described below. This analysis was done over a short (25 year) and long (100 year) time scale. The risk categories are as follows:

**Low risk**: A species or DPS is deemed to be at low risk of extinction if at least one of the following conditions is met:  The species/DPS has high abundance or productivity; There are stable or increasing trends in abundance; The distributional characteristics of the species/DPS are such that they allow resiliency to catastrophes or environmental changes.

**Moderate risk**: A species or DPS is deemed to be at moderate risk of extinction if it is not at high risk and at least one of the following conditions is met: There are unstable or decreasing trends in abundance or productivity which are substantial relative to overall population size; There have been reductions in genetic diversity; The distributional characteristics of the species/DPS are such that they make the species vulnerable to catastrophes or environmental changes.

**High risk**: A species or DPS is deemed to be at high risk of extinction if at least one of the following conditions is met at levels that place the persistence of the species at risk: The abundance of the species/DPS is such that depensatory effects are plausible; There are declining trends in abundance that are substantial relative to overall population size; There is low and decreasing genetic diversity; There are current or predicted environmental changes that may strongly and negatively affect a life history stage for a significant period of time; The species/DPS has distributional characteristics that result in vulnerability to catastrophes or environmental changes.

Table 5 below shows the SEDM results for the overall extinction risk for PBF on the short (25 year) and long (100 year) time scales with the highest score highlighted in grey.

**Table 5. Overall SEDM score distributions, means, and standard deviations for PBF. Numbers in left hand column indicate SRT members. Numbers are randomized and are not consistent throughout all tables in this document.**

| Overall PBF Extinction Risk Threat SEDM (25 years) | | | | Overall PBF Extinction Risk Threat SEDM (100 years) | | |
|---|---|---|---|---|---|---|
| | Low Risk | Moderate Risk | High Risk | Low Risk | Moderate Risk | High Risk |
| #1 | 90 | 10 | 0 | 80 | 20 | 0 |
| #2 | 60 | 40 | 0 | 55 | 45 | 0 |
| #3 | 50 | 50 | 0 | 10 | 35 | 55 |
| #4 | 80 | 10 | 10 | 70 | 20 | 10 |
| #5 | 100 | 0 | 0 | 75 | 25 | 0 |
| #6 | 80 | 20 | 0 | 60 | 35 | 5 |
| #7 | 15 | 70 | 15 | 10 | 75 | 15 |
| Mean | 67.86 | 28.57 | 3.57 | 51.43 | 36.43 | 12.14 |
| StDev | 28.85 | 25.45 | 6.27 | 29.54 | 19.30 | 19.76 |

Plausibility points were distributed across all three risk categories, however over the 25 year time frame, a large proportion were assigned to the low and moderate risk by some team members. Over the 100 year time frame, more points were assigned to the moderate and high risk categories. In both cases, the highest mean score was in the low risk category.

There are a number of factors that contributed to the low ranking of the overall extinction risk over both the 25 and 100 year time frames. The large number of mature individuals (>140,000), while small relative to the theoretical, model-derived unfished population, coupled with the overall population size (>1.6 million individuals), was deemed sufficient to allow PBF to avoid small population effects. In addition, the PBF population has experienced similarly low levels and has shown the ability to recover in the past, and is projected to increase in the current stock assessment. Harvest regulations have been adopted by member nations to reduce landings and rebuild the population. Also, the SRT noted that over the past 40 years the spawning stock biomass has experienced low levels relative to the theoretical, model-derived unfished population (less than 10% of unfished), and shown the ability to recover. While the SRT agreed that climate change has the potential to negatively impact the population, many members of the team felt that the PBF's broad distribution across habitat, vagile nature, and generalist foraging strategy were mitigating factors in terms of extinction risk.

However, although most likelihood points supported low risk at both time scales, some members put higher weight in the moderate and high risk categories, especially for the 100 year timeframe. The higher risk at this timeframe results from combining a number of factors each of which may have a relatively low chance of occurring but high uncertainty. When multiple risks are taken together the likelihood is increased that at least one of these factors could put PBF at moderate to high risk. For example, although it was pointed out above that PBF have demonstrated positive growth once from a low percentage of the number of adults, that has happened only once and little is understood about the conditions that resulted in that positive growth. Should PBF remain at very low levels of adults relative to theoretical unfished conditions *and* the species meets with a trend of poor conditions, for example increased temperatures in historical spawning grounds that result in only one suitable spawning ground with transport to areas poor for survival of young fish, PBF could be at increased risk. Since commercial fishing is the highest threat, uncertainty about the adequacy of management contributes to uncertainty about risk out to 100 years. Human populations are expected to continue to grow throughout the range of this highly valuable species and adequate management relies on international agreements and adequate policing of the high seas. With the exception of on board observer programs, there is currently little policing of domestic markets, and because fisheries models are entirely dependent on fisheries data, there are few checks and balances built into the management regime. Until a management process is demonstrated to be successful in rebuilding the species, the certainty with which long-term risk to PBF can be predicted is low.

While the SRT acknowledged the uncertainty associated with the concerns above, and while plausibility points were distributed among all categories, the majority of plausibility points were distributed in the low risk category.

## 8.0 RESEARCH NEEDS

The SRT identified several gaps in the knowledge base of PBF that at times contributed to the uncertainty associated with individual threats or threat categories. These gaps represented research needs that would improve not only our understanding of the basic biology of PBF, but also enhance the ability to fine-tune stock assessments. The list below (in no particular order) presents topics that would work towards the goal of improving our understanding of the PBF population as a whole. The SRT recognizes that some of these topics may currently be under study.

- Developing methodology to derive abundance indices that more accurately reflect the trend of abundance (e.g. applying spatio-temporal models of longline CPUE and length composition data).
- Improvements to the stock assessment model
- Identifying impacts of the IUU fishing loses or any unreported catch.
- A systematic biological sampling program across north Pacific to improve the estimates of growth parameters.
- Characterization of joint influences of environmental variability and fishing mortality on population sustainability.
- Physiological research on all life stages to assess impacts of climate change.
- Feeding ecology, e.g. impact of "prey switching" on condition, fitness etc.
- Fisheries independent estimate of spawning stock biomass.
- Quantitative characterization of movements around the Pacific and connectivity between spawning and foraging grounds.
- Improved recruitment index.
- Improved genetic study of potential population structure between spawning grounds.
- Study of spawning behavior.

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## 10. APPENDICES

Appendix Ia. Individual threat scoring table for the short time frame (25 years). Scores are presented for severity (S) and Certainty (C). Numbers above S/C scores represent each member of the SRT. These numbers are randomized and not consistent in all tables of this report.

| | | #1 | | #2 | | #3 | | #4 | | #5 | | #6 | | #7 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ESA Section 4(a)(1) Category** | **Specific Threat** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **Mean S** | **Mean C** | **SdevS** | **SdevC** |
| Habitat destruction, modification or curtailment | Water Pollution | 1 | 1 | 1 | 2 | 0 | 2 | 0 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0.43 | 1.43 | 0.53 | 1.13 |
| | Plastic Pollution | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0.00 | 1.71 | 0.00 | 1.25 |
| | Oil and Gas Development | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0.00 | 1.43 | 0.00 | 1.13 |
| | Wind Energy Development | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 3 | 0 | 3 | 0 | 1 | 0 | 0 | 0.00 | 1.71 | 0.00 | 1.11 |
| | Large-Scale Aquaculture | 1 | 1 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 3 | 0 | 1 | 1 | 0 | 0.29 | 1.43 | 0.49 | 0.98 |
| | Prey Depletion | 1 | 1 | 1 | 2 | 1 | 2 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 0 | 0.71 | 1.43 | 0.49 | 0.79 |
| Overutilization: commercial, recreational, scientific, educational | Commercial Fishing | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 1 | 2.29 | 2.43 | 0.49 | 0.79 |
| | Recreational Fishing | 1 | 2 | 1 | 3 | 0 | 2 | 0 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 0.71 | 2.14 | 0.49 | 0.69 |
| | IUU Fishing | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 2 | 1 | 0 | 2 | 0 | 1.14 | 0.86 | 0.69 | 0.69 |
| | Commercial Aquaculture Grow-Out | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 0 | 1.57 | 2.00 | 0.53 | 1.00 |
| | Commercial Closed-Cycle Aquaculture | 1 | 2 | 0 | 3 | 0 | 2 | 0 | 2 | 0 | 2 | 1 | 3 | 1 | 0 | 0.43 | 2.00 | 0.53 | 1.00 |
| | Scientific/Educational Take | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0.00 | 1.57 | 0.00 | 1.13 |
| Disease or Predation | Disease | 1 | 1 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 2 | 1 | 0 | 1 | 0 | 0.43 | 1.00 | 0.53 | 0.82 |
| | Predation | 0 | 2 | 0 | 3 | 0 | 1 | 0 | 1 | 0 | 3 | 1 | 1 | 1 | 0 | 0.29 | 1.57 | 0.49 | 1.13 |
| Inadequacy of existing regulatory mechanisms | International Management | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 0 | 3 | 0 | 3 | 2 | 1 | 1.29 | 2.29 | 0.95 | 0.76 |
| | Domestic Management | 1 | 3 | 0 | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 1 | 1 | 1 | 0.29 | 2.29 | 0.49 | 0.95 |
| Other natural or manmade factors | Climate Change - Ocean Acidification | 0 | 1 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 2 | 1 | 1 | 0.14 | 1.57 | 0.38 | 0.53 |
| | Climate Change - Dissolved Oxygen | 1 | 1 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 1 | 1 | 0.29 | 1.71 | 0.49 | 0.49 |
| | Climate Change - SST Rise | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 2 | 0 | 2 | 1 | 3 | 1 | 1 | 0.71 | 1.86 | 0.49 | 0.69 |
| | Climate Change - Food Web Alteration | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 0 | 1 | 2 | 1 | 0.86 | 1.43 | 0.69 | 0.53 |
| | Fukushima Associated Radiation | 0 | 2 | 0 | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0.00 | 1.86 | 0.00 | 1.35 |
| Small population concerns | Allee Effects | 1 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 0.71 | 1.00 | 0.76 | 0.58 |
| | Demographic Stochasticity | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 3 | 1 | 1 | 0 | 0 | 1 | 1 | 0.57 | 1.14 | 0.53 | 0.90 |
| | Genetics | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 3 | 1 | 2 | 0 | 0 | 1 | 1 | 0.43 | 1.43 | 0.53 | 0.98 |
| | Stochastic and Catastrophic Events | 1 | 0 | 0 | 2 | 1 | 2 | 0 | 3 | 0 | 2 | 0 | 0 | 1 | 1 | 0.43 | 1.43 | 0.53 | 1.13 |

Appendix I b. Individual threat scoring table for the long time frame (100 years). Scores are presented for severity (S) and Certainty (C). Numbers above S/C scores represent each member of the SRT. These numbers are randomized and not consistent in all tables of this report.

| **ESA Section 4(a)(1) Category** | **Specific Threat** | #1 | | #2 | | #3 | | #4 | | #5 | | #6 | | #7 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **S** | **C** | **Mean S** | **Mean C** | **SdevS** | **SdevC** |
| Habitat destruction, modification or curtailment | Water Pollution | 1 | 1 | 1 | 1 | 0 | 2 | 0 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 0.71 | 1.14 | 0.49 | 0.90 |
| | Plastic Pollution | 0 | 2 | 1 | 1 | 0 | 2 | 0 | 2 | 0 | 3 | 1 | 0 | 1 | 0 | 0.43 | 1.43 | 0.53 | 1.13 |
| | Oil and Gas Development | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 3 | 1 | 0 | 1 | 0 | 0.29 | 1.29 | 0.49 | 1.11 |
| | Wind Energy Development | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 3 | 0 | 3 | 1 | 1 | 1 | 0 | 0.29 | 1.57 | 0.49 | 1.13 |
| | Large-Scale Aquaculture | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 0.57 | 1.00 | 0.53 | 0.58 |
| | Prey Depletion | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 0 | 1.29 | 1.14 | 0.49 | 0.69 |
| Overutilization: commercial, recreational, scientific, educational | Commercial Fishing | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 2 | 3 | 2 | 0 | 3 | 1 | 2.43 | 1.29 | 0.53 | 0.95 |
| | Recreational Fishing | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 1 | 0.86 | 1.00 | 0.38 | 0.58 |
| | IUU Fishing | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 2 | 1 | 0 | 2 | 0 | 1.14 | 1.00 | 0.69 | 0.82 |
| | Commercial Aquaculture Grow-Out | 2 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 1.43 | 1.14 | 0.53 | 1.07 |
| | Commercial Closed-Cycle Aquaculture | 1 | 2 | 0 | 3 | 0 | 2 | 1 | 1 | 0 | 2 | 1 | 0 | 1 | 0 | 0.57 | 1.43 | 0.53 | 1.13 |
| | Scientific/Educational Take | 0 | 2 | 0 | 2 | 0 | 2 | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0.14 | 1.43 | 0.38 | 1.13 |
| Disease or Predation | Disease | 1 | 1 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 1 | 0 | 0.71 | 1.00 | 0.49 | 0.82 |
| | Predation | 0 | 2 | 0 | 2 | 0 | 1 | 1 | 1 | 0 | 3 | 1 | 1 | 1 | 0 | 0.43 | 1.43 | 0.53 | 0.98 |
| Inadequacy of existing regulatory mechanisms | International Management | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 0 | 3 | 0 | 0 | 3 | 1 | 1.43 | 1.29 | 1.13 | 0.95 |
| | Domestic Management | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 3 | 0 | 0 | 1 | 1 | 0.57 | 1.29 | 0.53 | 0.95 |
| Other natural or manmade factors | Climate Change - Ocean Acidification | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1.29 | 1.29 | 0.49 | 0.49 |
| | Climate Change - Dissolved Oxygen | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1.57 | 1.57 | 0.53 | 0.53 |
| | Climate Change - SST Rise | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 0 | 2 | 1 | 3 | 1 | 1 | 1.00 | 1.86 | 0.58 | 0.69 |
| | Climate Change - Food Web Alteration | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1.57 | 1.43 | 0.53 | 0.53 |
| | Fukushima Associated Radiation | 0 | 3 | 0 | 3 | 0 | 2 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0.00 | 2.00 | 0.00 | 1.41 |
| Small population concerns | Allee Effects | 1 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 0.71 | 0.86 | 0.76 | 0.69 |
| | Demographic Stochasticity | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 3 | 1 | 1 | 0 | 0 | 1 | 1 | 0.57 | 1.14 | 0.53 | 0.90 |
| | Genetics | 1 | 1 | 0 | 1 | 0 | 2 | 0 | 3 | 1 | 2 | 0 | 0 | 1 | 1 | 0.43 | 1.43 | 0.53 | 0.98 |
| | Stochastic and Catastrophic Events | 1 | 0 | 0 | 2 | 1 | 2 | 0 | 3 | 0 | 2 | 0 | 0 | 2 | 1 | 0.57 | 1.43 | 0.79 | 1.13 |

Appendix II. SEDM scores for individual threats where initial rankings differed substantially among team members. The highest mean score (dark grey) was used as the final ranking. Numbers in the left column represent each member of the SRT. These numbers are randomized and not consistent in all tables of this report.

| | 0 | 1 | 2 | 3 | | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| IUU Fishing (25 years) | | | | | IUU Fishing (100 years) | | | | |
| #1 | 50 | 50 | 0 | 0 | #1 | 40 | 45 | 15 | 0 |
| #2 | 0 | 20 | 60 | 20 | #2 | 0 | 20 | 60 | 20 |
| #3 | 5 | 20 | 50 | 25 | #3 | 5 | 20 | 50 | 25 |
| #4 | 45 | 40 | 15 | 0 | #4 | 45 | 40 | 10 | 5 |
| #5 | 25 | 60 | 15 | 0 | #5 | 40 | 40 | 20 | 0 |
| #6 | 20 | 60 | 20 | 0 | #6 | 10 | 60 | 30 | 0 |
| #7 | 20 | 75 | 8 | 0 | #7 | 20 | 75 | 5 | 0 |
| Mean | 23.6 | 46.4 | 24.0 | 6.4 | Mean | 22.9 | 42.9 | 27.1 | 7.1 |
| International Management (25 years) | | | | | International Management (100 years) | | | | |
| #1 | 10 | 20 | 70 | 0 | #1 | 10 | 20 | 70 | 0 |
| #2 | 0 | 30 | 60 | 10 | #2 | 0 | 10 | 60 | 30 |
| #3 | 10 | 80 | 10 | 0 | #3 | 0 | 20 | 60 | 20 |
| #4 | 80 | 20 | 0 | 0 | #4 | 55 | 45 | 0 | 0 |
| #5 | 30 | 30 | 40 | 0 | #5 | 30 | 30 | 40 | 0 |
| #6 | 80 | 20 | 0 | 0 | #6 | 70 | 20 | 10 | 0 |
| #7 | 10 | 80 | 10 | 0 | #7 | 15 | 70 | 15 | 0 |
| Mean | 31.4 | 40.0 | 27.1 | 1.4 | Mean | 25.7 | 30.7 | 36.4 | 7.1 |
| SST Rise (25 years) | | | | | SST Rise (100 years) | | | | |
| #1 | 90 | 10 | 0 | 0 | #1 | 40 | 50 | 10 | 0 |
| #2 | 0 | 60 | 30 | 10 | #2 | 0 | 50 | 30 | 20 |
| #3 | 25 | 50 | 25 | 0 | #3 | 10 | 30 | 30 | 30 |
| #4 | 60 | 30 | 10 | 0 | #4 | 70 | 20 | 10 | 0 |
| #5 | 25 | 30 | 35 | 10 | #5 | 25 | 30 | 35 | 10 |
| #6 | 40 | 50 | 10 | 0 | #6 | 20 | 50 | 30 | 0 |
| #7 | 0 | 60 | 40 | 0 | #7 | 0 | 60 | 35 | 5 |
| Mean | 34.3 | 41.4 | 21.4 | 2.9 | Mean | 23.6 | 41.4 | 25.7 | 9.3 |