Sustainable Indian Ocean Tuna Initiative

Echebastar Sustainability Working Group

ANALYSIS OF THE INTERACTION OF THE PURSE SEINE TUNA FISHERY IN THE INDIAN OCEAN WITH THE ECOSYSTEM AS DEFINED BY THE MSC STANDARD FOR SUSTAINABLE FISHERIES COMPONENT 2.5

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Final Report

March 2021

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ACRONYMS

AGAC	Association of Large Freezer Tuna Vessels
ALDFG	Abandoned, lost or otherwise discarded fishing gear
aFAD	Anchored Fishing Aggregating Device
APECOSM	Apex Predator Ecosystem model
BRP	Biological Reference Points
C	Component (MSC)
CAP	Client Action Plan (MSC)
CDR	Client Draft Report (MSC)
CEH	Commonly Encountered Habitats
CFTO	Compagnie Française du Thon Océanique
dFAD	Drifting Fishing Aggregating Device
ENSO	El Niño Southern Oscillation
EPO	Eastern Pacific Ocean
ESWG	Echebastar Sustainability Working Group
ETP	Endangered, Threatened and Protected species
EwE	Ecopath with Ecosim
FSC	Free School sets
HCR	Harvest Control Rules
HCT	Harvest Control Tools
HS	Harvest Strategy
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic tuna
IO	Indian Ocean
IOTC	IO Tuna Commission
MSC	Marine Stewardship Council
P	Principle (MSC)
PI	Performance Indicator (MSC)
PRI	Points of Recruitment Impairment
RFMO	Regional Fisheries Management Organisation
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SI	Scoring Issue (MSC)
SIOTI	Sustainable IO Tuna Initiative
ToR	Terms of Reference
UoA	Unit of Assessment
UoC	Unit of Certification
VME	Vulnerable Marine Ecosystem
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	West Central Pacific Ocean
WIO	Western Indian Ocean
WPEB	Working Party on Ecosystems and Bycatch

EXECUTIVE SUMMARY

The aim of the Fishery Improvement Project (FIP) of the Sustainable Indian Ocean Tuna Initiative (SIOTI) is to improve the sustainability credentials of its producer members so that they may meet the MSC Standard for Sustainable fisheries. The initial pre-assessment of the fishery found that it did not fully meet the Standard related to its interaction with the ecosystem (Component (C) 2.5), and this remained the case following the formal audit of the FIP by Fish Choice at the end of the third year of implementation. Accordingly, SIOTI commissioned this consultancy to establish the issues that may prevent certification and support definition of an effective work plan.

Echebastar is the only SIOTI member with an MSC certified fishery. The Echebastar Indian Ocean Skipjack Tuna Purse Seine Fishery setting on Free school (FSC) and drifting Fishing Aggregating Devices (dFAD) was certified against the Marine Stewardship Council (MSC) Fishery Standard (Standard) in November 2018. Eight binding conditions were defined on the certification, including one (Condition 5) on PI 2.5.3 -Ecosystem Information that achieved a score of 75. The audit team concluded that information and knowledge lacked on (i) the ecological impact of Echebastar removals on the trophic structure of the ecosystem, and (ii) the impact of its dFADs on the behaviour, feeding and migration of tuna.

Due to harmonisation requirements, Echebastar serves as a model for other SIOTI fisheries entering the MSC assessment process, while the company wishes to meet all of the conditions to its certification. Accordingly, it has promoted and supported the consultancy with the objectives of (i) clarifying the needs of the Standard in relation to C2.5 and (ii) providing evidence that would support the conclusion that its fishery achieves a minimum score of 80 for each of that components performance indicators.

An increasing number of purse seine tuna fisheries are MSC certified or are in the assessment process. The experience of these processes indicates a degree of misunderstanding and uncertainty when assessing a fishery against C2.5. In some cases, there have been issues in identifying the approach to scoring C2.5, how a fishery may meet the Standard, and, where required, respond to any defined condition (Sieben, Gascoigne & S. 2019; Stokes & Rios J 2020).

In addition, there have been difficulty in differentiating the separate issues to be considered under C2.5 and C2.4 (habitat) due to perceived cross cutting issues between the two in the context of purse seine tuna fisheries with dFADs (Juan-Jordá 2019).

In responding to the need to (i) clarify the approach to C2.5 (ii) harmonize scoring and rationales between MSC certified fisheries; and (iii) advise prospective MSC assessments for SIOTI producer members, a consultancy with the following objectives was commissioned.

- Confirm the requirements to meet the MSC standard for C 2.5.
- Identify the key ecosystem elements relevant to purse seine dFAD fisheries.
- Assess the current understanding of potential impacts of purse seine dFAD fisheries on key ecosystem elements taking into consideration generic ecosystem research, other fishing regions, and existing MSC assessments.
- Advise SIOTI on the activities required its members' fisheries to meet the MSC standard at PI2.5.1 and PI2.5.3 and the implications for any client action plan responding to conditions, bearing in mind that consideration of this component is limited to the impact of the UoA.
- Identify potential issues for C2.5 related to other fishing methods i.e., Anchored FADs (aFAD) and fishing on logs.

Section 2 of this report (i) puts C2.5 in context with a review and broad interpretation of the entire Standard and (ii) provides a comprehensive review of C2.5. The former identifies five potential interactions and cross cutting issues between P2 PIs. The latter (i) identifies 9 potential ecosystem impacts that may be considered under C2.5 (ii) considers their potential to cause serious or irreversible harm on the structure and function of the ecosystem, and (iii) reviews their relevance in the context of purse seine tuna fisheries.

Section 3 describes the main types of ecosystem impacts from purse seine fishing that may be subject of consideration under C2.5. These are:

- The ecological impacts of fishery removals of top predators (tunas and non-tunas) on the structure and function of marine ecosystem.
- The effect of natural environmental variability (including climate change) on ecosystem productivity and tuna dynamics.
- The ecological impact of dFAD use on the genetic, biology and ecology of species (tunas and non-tunas) on the genetic, biology and ecology of species, and
- The ecological impact of introducing marine debris via microplastics from abandoned, lost or discarded fishing gears on the food web.

It goes on to define a basic four-step guideline to facilitate C2.5 assessment of tuna purse seine fisheries.

- The types of ecosystem impact that should be identified and described prior to in-depth assessment.
- The main features or attributes of the ecosystems to be understood and monitored to evaluate each type of ecosystem impact.
- Identify the tools, the type of ecosystem indicators (and ecosystem models) needed to evaluate each of the ecosystem impacts.
- Identify the type of data and sources of data needed to develop indicators and ecosystem models to inform the evaluation of impacts.

Section 4 examines the C2.5. scoring rationales of 13 MSC assessments of purse seine fisheries targeting tropical tuna species setting on FSC and dFADs to. The 13 include a mix of MSC final reports and Comment Draft Reports for fisheries in the Atlantic, Pacific and Indian Oceans (AO, PO & IO).

All 13 evaluated the ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of marine ecosystem. Five of them evaluated the effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and the dynamics of predatory tunas, while three considered the effects of climate change on ecosystem productivity and tunas. Except for two FAD fisheries, all assessments assessed the ecological impact of FAD use via selective fishing on the genetic, biology and ecology of the targeted tunas. Only two of the assessments considered the ecological impact of FAD use via selective fishing on the genetic, biology and ecology of non-tunas (non-target catches such as sharks). None of the assessments considered the ecological impact of fishing via the introduction of microplastic pollution from fishing gear into the food web.

Section 5 synthesizes past and on-going research from the IO, PO and AO to provide evidence on the potential ecosystem impacts from purse seine fisheries (FSC and dFADs) on the structure and function of marine ecosystems. This allows identification of the purse seine fisheries with adequate information and detailed study on ecosystem impacts, and those for which the impacts have not been investigated in detail and are poorly understood. In summary,

- The ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of the marine ecosystem have been relatively well investigated and understood in the EPO and WPO, while the opposite is the case for the AO and IO.
- The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the truncation of size composition or via the alteration of diversity on the structure and function of marine ecosystem have not been investigated in detail and remain poorly understood in all the oceans, with few exceptions.
- The effect of large scale climatic and oceanographic physical forcing, including climate change, on ecosystem productivity and the dynamics of tunas have been relatively well investigated and some aspects are well understood, yet it remains to connect this pool of knowledge with operational fisheries management.
- The ecological impact of FAD use via selective fishing on the genetic, biology and ecology of the targeted tropical tunas has been increasingly studied, yet there remains major gaps in knowledge.
- There has been considerable research (experimental tagging studies, and studies using fisher's echosounder buoy data) examining the effects of FADs (mostly presence of dFADs) on the behaviour, movement patterns of tunas and their consequences on the biology of the species (e.g., growth). More studies are required, however, to understand better the effects of increasing number of dFADs and FAD densities on the behaviour, movement patterns of tunas.
- Comparatively the ecological impact of FAD use on the genetic, biology and ecology of the non-targeted tunas (e.g. sharks) remains poorly known, yet it is an expanding field of research.

Section 6 examines existing research and assesses whether or not there is adequate information on the impacts of the Echebastar fishery on individual key ecosystem elements to allow some of the main consequences to be inferred.

The report highlights how the lack of solid research and ecosystem modelling (trophic-based or size-based ecosystem models) for the IO prevents detailed investigation of the impact of biomass removals of all fisheries combined (or the relative removals by Echebastar) on the ecosystem structure and function, and to assess if these effects are causing serious or irreversible harm in the marine ecosystem in the IO.

Accordingly, informed understanding of the pelagic food web dynamics and the impact of fishing must be derived from the PO where most of the ecosystem modelling in the context of tuna fisheries has been carried out.

The lack of specific ecosystem indicators and ecosystem models in the IO makes it difficult to simulate and infer the main consequences of the impacts of the Echebastar fishery on the ecosystem. This means there is no hard evidence that it is highly unlikely to disrupt the key elements of the ecosystem.

Considerable research has been completed to understand how natural environmental variability and climate change affect the dynamics of top predatory species such as tunas in the IO. More research and ecosystem modelling are needed however to evaluate different environmental and climate scenarios, in combination with different fishing scenarios, and their effect on the dynamics of top predatory species. This would allow the main consequences of environmental changes and fishing on the ecosystem to be inferred.

The report also highlights there have been an increasing number of experimental studies investigating the effects of dFADs on pelagic species behaviour and movement patterns in the PO and IO. There remains limited understanding on (i) the influence of dFADs on the residency of tunas and other non-tuna species, and (ii) how the increased number of dFADs may affect the school sizes of tunas and other species.

Accordingly, there remain conflicting interpretations and results on the behavioural impacts of dFADs (and the different densities of dFADs) on tunas and related species and potential consequences on their biology. This lack of understanding makes it difficult to infer all the main consequences of the impact of dFAD use on tuna species, and even more so on non-tuna species such as sharks for which research is even more limited.

In perspective, as the Echebastar fishery only accounts for a small proportion (about 12 %) of the dFADs deployed in the IO, it may be inferred that it is highly unlikely to disrupt the behaviour, movements patterns and condition of pelagic species to a point where there would be a serious irreversible hard. Yet there is no hard evidence of this.

Section 7 provides a shadow scoring for PI 2.5.1 and PI 2.5.3 for the Echebastar purse seine fishery considering the identified three main types of ecosystem impact. Both achieved scores of 80. It is emphasised that while this outcome may advise auditors in any assessment or surveillance audit, they are not obliged to accept the findings of the consultant.

Section 8 presents conclusions.

Review and analysis comprises a number of issues that: (i) inform SIOTI its potential C2.5. work plan for the remaining two years of its fishery improvement project (FIP) in relation to meeting the Standard for each of the three Pis that comprise C2.5; (ii) identify where SIOTI may support IOTC in implementing an ecosystem approach to fisheries management (EAFM) in tuna fisheries in the IO; (iii) provide Echebastar with evidence to submit to the MSC second annual surveillance audit that the fishery can meet its PI2.5.3 condition to certification; and (iv) provide evidence to other SIOTI member fisheries that are in the MSC assessment process. Additionally, the consultant makes a number of suggestions of where SIOTI could make representations to MSC on changes in the Standard.

The scoring in the context of the Echebastar assessment, indicate that all SIOTI related UoA could meet the Standard in relation to C2.5. However, it should be borne in mind that any CAB auditors would complete an independent assessment. At this stage, it would seem opportune to await the outcome of the CFTO assessment and see if this has scores for C2.5 PIs that are different from those gained by Echebastar.

C2.5 relates to the situation for each of the IO purse seine tuna fisheries (yellowfin, skipjack and bigeye) and SIOTI may not need related activities designed to achieve a score of 80 for each of the individual PIs.

As noted, C2.5 only relates to the impact of the UoA/UoC on the ecosystem. While cumulative fishing impacts of overlapping MSC fisheries in relation to C2.5 are not currently relevant, such impacts on ETP species, habitats and ecosystem structure and function are considered by the IOTC Working Party of Bycatch and Ecosystem to provide more integrated advice to inform the implementation of EAFM. It appears clear that EAFM will become more relevant to the management of IO tuna fisheries. Accordingly, SIOTI may wish to support basic ecosystem research to better understand and quantify the different ecological impacts of purse seine fisheries on the structure and function of marine ecosystems and inform the implementation the EAFM, with:

- Enhanced data collection in the observer programs:

- Fish stomachs and fish samples to support research on the trophic ecology of species (tunas and non-tunas) using traditional (stomach and isotope analyses) and new techniques (DNA metabarcoding), and support the development of trophic-based indicators and trophic-based ecosystem models.
    - Size-based data for tunas and non-tunas to support the development of community size-based indicators and ecosystem models.
    - Support research on the basic biology and life history (growth, reproduction) of pelagic species (tunas and non-tunas).
- Recommend to IOTC:
    - Empirically based ecosystem indicators to monitor the ecological impacts of fisheries on the ecosystem structure and function of marine ecosystems.
    - Specialised technical workshops and joint collaborative analyses to produce ecosystem assessments.
    - Ecosystem models and their use to evaluate alternative management scenarios of fishing. Ecosystem models can also assist in investigating the effect of environmental and climate-based scenarios (in combination of fishing scenarios) on the population dynamics of tuna species, and project changes in tuna distributions in response to climate change.
    - A feasibility study to identify the different types of data inputs required by each ecosystem model platform (i.e. EwE, SEAPODYM, APESCOM,etc.), identify data gaps and other potential factors hindering ecosystem modelling in the IO.
    - A data collection plan to support ecosystem modelling, and identify the required actions to initiate ecosystem modelling.
- Support the concept of an IOTC ocean-climate web to encourage further research and studies on the role and influence of climate and environment, including climate change, on the population dynamics, movement, abundance of main IOTC species (Marsac & Marbec 2018; Marsac & Shahifar 2019).
- Propose to IOTC adaptive management plans that respond to environmental changes and climate change.
- Support studies of the interactions between species and FADs to investigate the:
    - Fine-scale associative behaviour of tunas and non-tuna species such as silky sharks and oceanic-whitetip shark to dFADs and how these are affected by fishing area, environmental conditions and food resources.
    - FAD colonization and decolonization rates of tunas and non-tuna species using acoustic and archival tags as well as echo-sounder buoys and how these are affected by environmental conditions, food resources and FAD characteristics.
    - Effects of increasing number of FADs and FAD densities on the behaviour and biology of the species being aggregated around FAD.
- Support initiatives to use FADs as scientific platforms and as a network of autonomous observation stations to inform research.
- Support biological, life history and habitat studies of silky sharks to inform behavioural studies and bycatch mitigation techniques in FAD-associated purse seine fisheries.

In completing the work, the consultant identified a number of factors that may influence an assessment of C2.5. While, these are outside the scope of the study, and it is acknowledged that the MSC has a defined approach to monitoring and improving the Standard following robust stakeholder

consultation over an extended period, the following are areas where SIOTI may like to review to provide input into the MSC process.

- The Standard could improve guidelines to facilitate the identification of what type of ecosystem impacts need to be assessed under C2.5 (Ecosystems) and what key ecosystem elements would need to be monitored to assess those impacts.
- MSC assessments of C2.5 (Ecosystems) could define upfront the type of ecosystem impact to be evaluated and the key ecosystem elements to be examined.
- A harmonized approach to assessments may be facilitated through clarification of whether the impact of dFADs on the behaviour, movement patterns and biology of ETP species should be evaluated under P2.3.1 Sic or PI2.5.1.
- The Standard could expand C2.4 (Habitats) to include both the direct impacts and indirect impacts of fishing on habitats and ensure all potential ecological impacts of fishing on habitats are covered.
- The Standard could benefit from clarification of the meaning of VME in the context of the pelagic environment and pelagic fisheries. With VME as a habitat with a *functional significance* tuna spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate could be included. As such, it could be argued that the indirect impact of FAD use on the behaviour, condition, distribution and migration of species should be assessed under C2.4 rather than C2.5.
- The issue of marine debris is becoming more relevant to the analysis of sustainability in the context of EAFM and this should be proactively reviewed by SIOTI.
- ISSF recommends further research on the potential of FADs to act as ecological traps in pelagic species. ISSF could review its best practices and actions in relation to P2 Ecosystems, through consideration of a wider range of potential types of ecosystem impact while distinguishing between C2.4 and C2.5.

1. INTRODUCTION

The MSC Fisheries Standard (Standard) comprises three Principles (P) (MSC 2018):

- P1 relates to the status of the stock exploited in the fishery.
- P2 to the impact on the ecosystem from the fishery being assessed; and
- P3 to the fishery management system.

The aim of the Fishery Improvement Project (FIP) of the Sustainable Indian Ocean Tuna Initiative (SIOTI) is to improve the sustainability credentials of its producer members so that they may meet the MSC Standard for Sustainable fisheries. The initial pre-assessment of the fishery found that it did not fully meet the Standard related to its interaction with the ecosystem (Component (C) 2.5), and this remained the case following the formal audit of the FIP by Fish Choice at the end of the third year of implementation. Accordingly, SIOTI commissioned this consultancy to establish the issues that may prevent certification and support definition of an effective work plan.

The Echebastar IO Skipjack Tuna Purse Seine Fishery setting on Free school (FSC) and drifting Fishing Aggregating Devices (dFAD) gained MSC certificate in November 2018. Eight conditions to the certification were defined (Stokes & Rios J 2020).

One of the conditions was related to Performance Indicator (PI) 2.5.3 -Ecosystem Information that achieved a score of 75.[1] The scoring rational found:

- *"Given that the fisheries are industrial scale, not all interactions have been investigated in the detail needed to support an ecosystem-based approach to fisheries management. Possible changes in trophic structure of pelagic oceanic ecosystems have not been investigated in sufficient detail and there is ongoing uncertainty in relation to the role of tuna fisheries in reduction of top- level predators in the IO as well as an observed increase in the prevalence of lower trophic level pelagic species (Hallier and Gaetner, 2008).*
- *"The impact of dFADs on tuna behaviour, feeding and migration, and any consequent impacts on ecosystem function, is not fully understood. Therefore, adequate information is not available on the impacts of the Unit of Assessment (UoA) on these components to allow some of the main consequences for the ecosystem to be inferred".*

Accordingly, the related Condition to certification was:

- *SIb. By the fourth annual surveillance audit, the client must provide evidence that the main impacts of the dFADs used in the UoA/UoC on these key ecosystem elements can be inferred from existing information, and some have been investigated in detail.*
- *SId. By the fourth annual surveillance audit, the client must provide evidence that there is adequate information on the impacts of the UoA on these components to allow some of the main consequences for the ecosystem to be inferred.*

Some MSC assessments of purse seine tuna fisheries using dFADs have shown a degree of misunderstanding and uncertainty in relation to PI 2.5, with difficulties in scoring and how an Unit of Assessment (UoA) may meet the Standard, and, if required, respond to any condition (Sieben, Gascoigne & S. 2019; Stokes & Rios J 2020).

[1] This PI requires an adequate understanding of the elements of the ecosystem and their function, the impacts of the fishery being assessed on the broader ecosystem, the ecosystem role of the other P1 and P2 components (e.g. target species, ETP species) and the consequential impact of the fishery on those components on the broader ecosystem.

There have been some difficulties and confusion in assessing the ecosystems and habitat impacts of an UoA. These two components (C 2.4 and C2.5) may be related, giving rise to cross cutting issues in scoring them in purse seine tuna fisheries with dFADs (Juan-Jordá 2019).

Moreover, in relation to C2.5, the scoring rationales of two recent Comment Draft Reports (CDR) for MSC differ that for the Echebastar Unit of Certification (UoC).

- CFTO: PI 2.5.3 on three scoring issues (SI): (a) Information Quality (b) Investigation of UoA Impacts and (d) Information Relevance (Sieben, Gascoigne & S. 2019; Stokes & Rios J 2020).
- AGAC: PI 2.5.1 Prospective scoring (90 vs Echebastar 80) (Akroyd *et al.* 2020).

In responding to the need: (i) to clarify the approach to C2.5 (ii) harmonize scoring and rationales between MSC certified fisheries; and (iii) advise other prospective MSC assessments by SIOTI producer members, a consultancy with the following objectives was commissioned:

- Confirm the requirements to meet the MSC Standard for C 2.5.
- Identify the key ecosystem elements relevant to purse seine dFAD fisheries.
- Assess the current understanding of potential impacts of purse seine dFAD fisheries on key ecosystem elements taking into consideration generic ecosystem research, other fishing regions, and existing MSC assessments.
- Advise SIOTI on the activities required its members' fisheries to meet the MSC standard at PI2.5.1 and PI2.5.3 and the implications for any client action plan responding to conditions, bearing in mind that consideration of this component is limited to the impact of the UoA.
- Identify potential issues for C2.5 related to other fishing methods i.e., Anchored FADs (aFAD) and fishing on logs.

The Terms of Reference (ToR) are in Appendix A.

2. THE MSC STANDARD

2.1 The MSC Standard and requirements in the context of purse seine tuna fisheries

It is essential to consider what P1 and P2 broadly cover to put C2.5 Ecosystems into context.

P1 assesses the target species, while P2 covers other elements of the ecosystem: Primary Species (C2.1), Secondary Species (C2.2), ETP Species (C2.3), Habitats (C2.4) and Ecosystems (C2.5) (Figure 1). The two cover all potential ecosystem interactions between a fishery and the components of the two Principles, including direct and indirect interactions (Figure 1). They also consider the potential effects of environment and climate on the productivity of the ecosystem, and how such as natural variability and climate change may impact the population dynamics of the species and the fishery (Figure 1). However, the MSC approaches to P1 and P2 vary.

P1.

- This applies to the whole fish stock (i.e., target species) exploited by the UoA, covering: (i) in C1.1, the impact of all fishing activities on the defined target stock(s) (stock status and rebuilding strategy if applicable); and C1.2 fishery management (harvest strategy (HS), harvest control rules (HCR) and tools (HCT), information and stock assessment) (interaction 1 Figure 1).
- MSC recommends that P1 take into account the potential impacts of changes in ecosystem productivity (e.g., ocean warming) through adjustment of the biological reference points (BRP) of the Target Species so they are consistent with the ecosystem productivity (ecosystem interactions 2 Figure 1).

P2.

- This considers the impact of an UoA on other elements of the ecosystem.
- While the effect of the environment and climate as a driver of ecosystem productivity and dynamics cannot be controlled or managed by a fishery, analysis of some P2 PIs requires an understanding of their effect.
- The Primary Species, Secondary Species and ETP species interacting with the UoA are identified prior to assessment, with the Standard providing guidelines for their designation.
- C2.1 & C2.2 assess direct impacts by evaluating status, management and information. For a purse seiner this includes the by-catch as well as other sources of direct mortality such as discards or interactions with the fishing gear (ecosystem interactions 3, 4 and 5 Figure 1).
- C2.3 assesses for both direct and indirect impacts (such as noise, pollution or other fishery related parameters) (interaction 6 Figure 1). An indirect impact of purse seine tuna fisheries is the link between dFADs and the behaviour, distribution, migration and conditions of ETP species.
- C2.4 considers the direct impact of an UoA on the structure and function of the habitat[2] by evaluating the nature and extent of such impacts, whether any management in place is appropriate and there is reliable information on identified issues. The Standard considers Commonly Encountered Habitats (CEH), Vulnerable Marine Ecosystems (VME[3]), and Minor Habitats[4] that interact with the UoA.
- Purse seine fishing occurs entirely in the upper water column (epipelagic habitat - usually assessed as a CEH (ecosystem interaction 7 Figure 1) and the fishing gear does not come into contact with the seabed. However, dFADs may drift from the fishing grounds to coastal shallow waters where they may go aground into VME (e.g., coral reefs) (ecosystem interaction 8 Figure 1).
- Alternatively, they may eventually sink to the sea bottom. Such deep-water habitats are usually designated as a Minor Habitat (interaction 9 Figure 1).
- Individual P2 PIs (PI2.1.1, PI2.2.1, PI2.3.1 and PI2.4.2) consider the cumulative impacts of overlapping MSC certified fisheries. However, C2.5. does not take cumulative effects into account.

It is important to note that while the Standard refers to habitats (including pelagic habitats) with a functional significance as potential VMEs (e.g., nursery areas, feeding grounds for tunas or ETP species, and hotspot areas with high aggregation of biodiversity), it appears that no MSC assessment has considered this aspect.

P3 that assesses management of the fishery is not covered in this report.

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[2] The Standard describes Habitat as "*the chemical and bio-physical environment including biogenic structure, where fishing takes place*". These include habitats on the seabed and also the water column itself (e.g., the epipelagic or mesopelagic environment).

[3] The Standard (SA3.13.3.2) " *a VME shall be defined as is done in paragraph 42 subparagraphs (i)-(v) of the FAO Guidelines. Accordingly, the FAO provides guidance on the definition of a VME habitat, which essentially are those that are either (i) unique or rare, (ii) functionally significant, (iii) fragile, (iv) have life history traits that may male recovery difficult, or (v) are structurally complex. It is also important to consider that although the FAO guidelines on VME were written for deep-sea fisheries, the MSC Fishery Standard intent is that the FAO guidelines for designing VME are also applied to other type of fisheries such as pelagic fisheries*".

[4] Minor Habitats includes all other habitats which are not covered in the definition of CEH and VME.

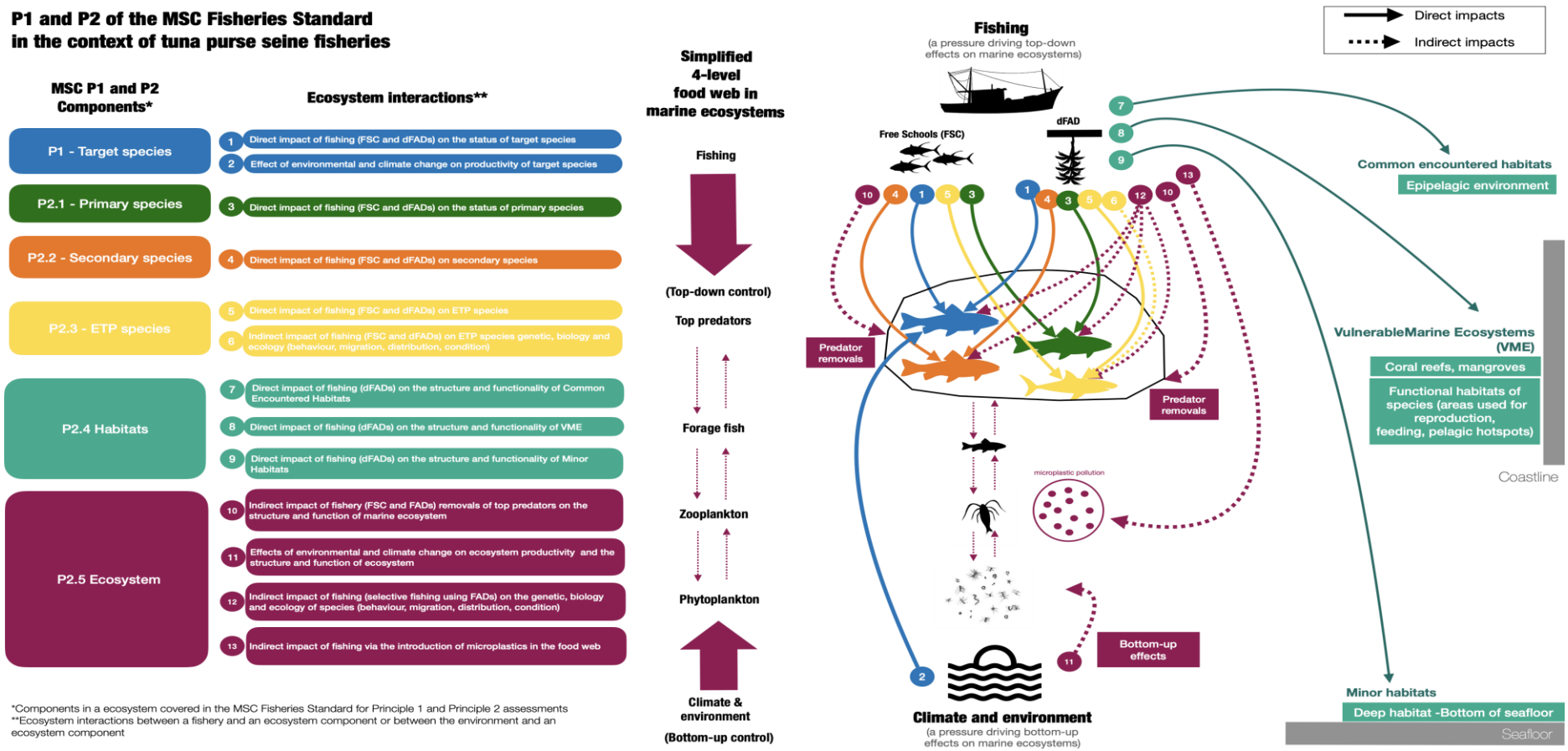

Figure 1: The main components of an ecosystem covered in the MSC P1 and P2 assessments showing the main interactions between the UoA and the ecosystem, including the direct and indirect impacts of fishing and the environment.

2.2 C 2.5 Ecosystem

2.2.1 *Introduction*

The Ecosystem Component does not consider the status of the other P2 components, rather it aims to capture the indirect impacts of fishing on the wider ecosystem structure and function.

P2.5 assesses whether:

- The UoA impacts the structure and function of ecosystems.
- Appropriate management is in place; and
- Appropriate information is available to complete the assessment. The Standard requires that the fishery does not cause "*serious or irreversible harm*" to "*key elements of the ecosystems*"[5] underlying ecosystem structure and function of marine ecosystems.

Unlike other P2 components, C2.5 allows some flexibility to decide what type of ecosystem impacts (or ecological impacts) are assessed, which depends on the nature of the UoA and the character of the ecosystem in the fishing area.

2.2.2 *Approach*

The Standard provides examples[6] of serious or irreversible harm in relation to the capacity of the ecosystem to deliver ecosystem services that provide some guidance to identify what type of ecosystem impacts that may be considered under C2.5.

Table 1 lists potential ecosystem impacts covering (i) the Standard examples and (ii) the potential types that may be relevant to a purse seine tuna fishery. The full analysis covers (i) Column 1 - those ecosystem impacts derived from fishing, (ii) Column 2 - their potential serious or irreversible harm and (iii) Column 3 – their relevance in the context of purse seine tuna fishing. Ecosystem interactions 10,11,12 and 13 in Figure 1 broadly cover all potential ecosystem impacts to be assessed under C2.5.

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[5] The Standard Table SA8 describes that "*serious or irreversible harm*" to the structure and function of marine ecosystems means changes caused by the UoA that fundamentally causes a "*reduction of key features most crucial to maintaining the integrity of its structure and functions and ensuring that ecosystem resilience and productivity is not adversely impacted. This includes, but is not limited to, permanent changes in the biological diversity of the ecological community and the ecosystem's capacity to deliver ecosystem services*". The MSC Outcome expectation for the P2.5 Ecosystem component is that if a fishery alters the fundamental capacity of the ecosystem to maintain its structure and function it has to be able to recover from its impact.

The Standard in SA3.16.3 describes "*key ecosystem elements" are the features of an ecosystem considered as being most crucial to giving the ecosystem its characteristic nature and dynamics, and are considered relative to the scale and intensity of the UoA. They are features most crucial to maintaining the integrity of its structure and functions and the key determinants of the ecosystem resilience and productivity*".

[6] *(i) "Trophic cascade (i.e., significantly increased abundance, and especially decreased diversity, of species low in the food web) caused by depletion of predators and especially 'keystone' predators; " (ii) "Depletion of top predators and trophic cascade through lower trophic levels caused by depletion of key prey species in 'wasp-waist' food webs; " (iii) "Severely truncated size composition of the ecological community (e.g., greatly elevated intercept and steepened gradient in the community size spectrum) to the extent that recovery would be very slow due to the increased predation of intermediate-sized predators; " (iv) "Gross changes in the species diversity of the ecological community (e.g., loss of species, major changes in species evenness and dominance) caused by direct or indirect effects of fishing (e.g., discarding which provides food for scavenging species); " (v) "Change in genetic diversity of species caused by selective fishing and resulting in genetically determined change in demographic parameters (e.g., growth, reproductive output)."*

Table 1: Potential ecosystem impacts to be considered under C2.5

Potential ecosystem impacts	Potential serious or irreversible harm	Relevance to purse seine tuna fisheries (FSC and dFADs)
1. The ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of marine ecosystem	Depletion of predators and especially keystone predators could cause trophic cascades via trophic relationships (i.e., significantly increased abundance, and especially decreased diversity, of species low in the food web) which could disrupt the overall balance of the ecosystem.	This may be relevant in the assessment of purse tuna fisheries that catch top predatory species[7]of different trophic levels and in varying quantities. The ecological impact of fishery removals of top predators will depend on their total catch and the species composition (the biological characteristics of the species being removed).
2. The ecological impacts of fishery removals of low-trophic level species (such as sardines, herring) via the alteration of trophic relationships on the structure and function of the marine ecosystem	The depletion of low-trophic level species, which are prey species of top predators, could deplete top predators via trophic relationships and create a trophic cascade through lower trophic levels.	This type of ecosystem impact is not relevant to purse seine tuna fisheries as these fisheries do not target low-trophic level species and any catch is minimal. It would be relevant to a pole and line fishery due to the capture of bait species.
3. The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the truncation of size composition on the structure and function of marine ecosystem.	Removing predators or important prey species could severely truncate the size composition of the ecological community (e.g., greatly elevated intercept and steepened gradient in the community size spectrum) to the extent that recovery of species could be slow.	This may be relevant in the assessment of purse tuna fisheries that catch top predatory species of assorted sizes and in varying quantities. The ecological impacts of fishery removals of top predators will depend on their total catch and the size composition of the species being removed.
4. The ecological impacts of fishery removals of species (either top predators or other species in the	Removing predators or important prey species could create cross changes in the species diversity of the	This may be relevant in the assessment of purse tuna fisheries as they catch top predatory species of different sizes and trophic levels and

[7] Target tunas and non-target tunas, billfishes and sharks

foodweb) via the alteration of diversity on the structure and function of marine ecosystem.	ecological community (e.g., loss of species, major changes in species evenness and dominance).	in varying quantities. The ecological impacts of fishery removals of top predators will depend on their total catch and the species composition (the biological characteristics of the species being removed).
5. The ecological impacts of selective fishing (specific sizes, species, behaviour) on the genetic, biology and ecology of species	Selective fishing (e.g., specific sizes, specific species, specific behaviour) could (i) change the biology and ecology of the species (alter their migration patterns, condition, behaviour), (ii) change the genetic diversity of species resulting for example in genetically determined change in demographic parameters (e.g., growth, reproductive output).	The ecological impacts of selective fishing via FAD fishing may be relevant in the assessment of purse tuna fisheries. FAD fishing has a selectivity pattern for specific sizes of species, specific behaviour and types of species. Tunas, especially in the smaller size range, as well as other pelagic species tend to aggregate under dFADs that have added a new selectivity component as only species associated to dFADs are selectively removed. The dFAD fishery may be causing competitive disadvantages to some species with genetic and ecological implications.
6. The effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and tuna dynamics	Environmental change can produce changes in productivity of the ecosystem and the fishery	This may be relevant in the assessment of purse tuna fisheries as the population dynamics of species can change in response to environmental change
7. The effects of climate change on ecosystem productivity and tuna dynamics	The increasing threat of climate change can produce changes in productivity of the ecosystem and the fishery	This may be relevant in the assessment of purse tuna fisheries as the population dynamics of species can change in response to climate change.
8. The ecological impacts of introducing invasive species	Invasive species may impact native ecosystems by competing with native species for resources, modifying habitats, predation of native species, introducing diseases, hybridizing with natives, leading to loss of genetic diversity.	This type of ecosystem impact is not relevant to purse seine tuna fisheries. There have been no documented cases of the introduction of invasive species related to such fishing operations.

9. The ecological impacts of introducing marine debris derived either from fishery activity (mainly abandoned, lost, or discarded fishing gears - ALDFG) or derived from vessel activity (mainly the litter generated by the boat).	ALDFG may generate different types of ecosystem impacts: (i) the entanglement of sensitive non-target species such as seabirds, turtles and shark on ALDFG (ghost fishing), or by the ingestion of it, resulting in increased mortality of those species, (ii) impacts on sensitive habitats (e.g. VME), (iii) due to the breakdown of plastic materials, microplastics are generated and the toxic substances contained are introduced throughout the food chain supposing a threat to the human health and the ecosystem, and (iv) the litter generated by the fishing boat if dumped overboard can also introduce waste into the marine ecosystem.	Some of these impacts may be relevant in the assessment of purse tuna fisheries, particularly those using dFADs. • The impacts of ALDFG on sensitivity non-target species (ETP species) by entanglement and ghost fishing are usually assessed under C2.3 (indirect impacts). • The impacts of ALDFG on sensitive habitats (e.g., VME) are usually assessed under C2.4 Habitats. • To our knowledge, the impacts of ALDFG via the introduction of toxics substances and microplastics in the food chains has not been considered in MSC assessments. • The generation of litter by purse seine fisheries may be a subject of consideration under C2.4 Habitats.

In addition to direct and indirect impact of fisheries on the marine ecosystem, the Standard also recognizes that the productivity of the fisheries may be affected by a range of environmental and oceanographic drivers, including the emergent threat of climate change on marine ecosystems. Guidance on scoring environmental changes and climate change impacts is provided PI2.5.3[8].

MSC guidelines also consider the effects of environmental variability (including climate change) that may be a type of ecological important assessed under PI 2.5.3.

2.2.3 *C2.5 potential misinterpretations and cross cutting issues with other P2 components*

Review of the Standard identified several potential interactions and cross cutting issues between P2 PIs

- **Indirect impacts of fishing on ETP species.** Under C2.3, ETP species are assessed for both direct and indirect impacts of fishing. The Standard notes that the latter could consider noise, pollution or other threats derived from the fishery (and fishing activity). However, for purse seine tuna fisheries also relevant are the potential ecological impacts of dFADs on the behaviour, distribution, migration, and conditions of ETP species. However, this is commonly subject to assessment under C2.5 which may lead to some misinterpretation between C2.3 and C2.5.

- **A VME with a functional significance.** Following FAO guidelines, the Standard describes a potential VME as a habitat with a functional significance i.e., "*discrete areas or habitats that are necessary for survival, function, spawning / reproduction, or recovery of fish stocks; for particular life- history stages (e.g., nursery grounds, rearing areas); or for ETP species"*

  This could be interpreted as areas used by tuna and tuna-like species for spawning, migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate at a particular time. It seems that, to-date, no MSC tuna assessment has considered VMEs with a functional significance, although the Standard recognizes VME in the pelagic habitats as worth of assessment if deemed relevant. The use of dFADs in purse seine fisheries might impact how tuna and related species use pelagic habitats for spawning, migrating, and feeding, and this may have ecological implications for the distribution, migration, behaviour, and condition of species.

  While the evaluation of the impacts of FAD use on the behaviour, distribution, migration, and condition of species is commonly done under C2.5, this interpretation of pelagic habitats as potential VME of functional significance for some species may lead to some misinterpretation between C2.4 and C2.5.

- **The multiple dimensions of marine debris.** Purse seine tuna fisheries, particularly those using dFADs, can generate abandoned, lost or discarded fishing gears (ALDFC). ALDFG

[8] Focus on the main interactions between the UoA and these ecosystem elements" at the SG100 level … should consider: "*(i) UoAs should be capable of adapting management to environmental changes as well as managing the effect of the UoA on the ecosystem". "(ii) Monitoring the effects of environmental change on the natural productivity of the UoAs should be considered best practice and should include recognition of the increasing importance of climate change"* (SA3.18.1.2)

can generate four distinct types of ecosystem impacts: (i) The impacts of ALDFG on sensitivity non-target species (ETP species) by entanglement and ghost fishing. This may be assessed under C2.3 in the assessment of the indirect impact of the fishery on the ETP species. (ii) The impacts of ALDFG on sensitive habitats (e.g., dFADs impacts on coral reefs as VME), which may be assessed under C2.4. (iii) Purse seine fisheries (FSC and dFADs) may also generate marine litter that if not managed well could be disposed into the ecosystem. This impact may be assessed under PI 2.4 if the marine litter impacts habitats. (iv) The potential impacts of ALDFG via the introduction of toxics substances and microplastics throughout the food chains. While this type of impact has not been subject of MSC assessments of tuna fisheries (to our knowledge), this may change with any impact assessed under C2.5. Accordingly, row 8 of Table 1 considers this issue.

- **Treatment of cumulative impacts in P2 assessments.** As noted above, the cumulative impacts of overlapping MSC UoCs are evaluated under P2 components except for C2.5. This may lead to some potential misinterpretations in an MSC assessment of P2.

3. THE TUNA PURSE SEINE FISHERY: MAIN INTERACTIONS WITH KEY ECOSYTEM ELEMENTS

3.1 Approach

The main types of ecosystem impact from purse seine fishing that may be subject of consideration under C2.5 were described. Of the total of 9 types identified in Section 2, 7 are judged relevant to an assessment of a purse seine tuna fishery. These are grouped into four main types to frame them together with those impacts covered under P1 and P2 (see interaction 10, 11, 12 and 13 in Figure 1).

A four-step basic guideline is also presented to facilitate the assessment of the ecosystem impacts from purse seine fishing under C2.5.

3.2 Main types of ecosystem impacts

3.2.1 *The ecological impacts of fishery removals of top predators*

Rational: Depletion of predators and especially keystone predators could (i) cause trophic cascades via trophic relationships to the extent that it could disrupt the overall balance of the ecosystem, (ii) severely truncate the size composition of the ecological community to the extent that recovery of species could be slow, and (iii) create gross changes in the species diversity of the ecological community (e.g., loss of species, major changes in species evenness and dominance) to the extent that it could disrupt the overall balance of the ecosystem (National Research Council 2006; Shannon *et al.* 2014b; Coll *et al.* 2016a; Bundy, Gomez & Cook 2017; Fulton *et al.* 2019).

Relevance for purse seine tuna fisheries: This impact may be considered in MSC assessments of purse tuna fisheries that capture top predatory species (mainly the target tropical tunas, and some non-target tunas, billfishes and sharks) of varying size, trophic level and quantities. The potential ecological impact of fishery removals of top predators will depend on the quantity of the species removed, the species composition being removed, and the size composition of the species being removed (Hampton *et al.* 2005; Polacheck 2006; Gerrodette *et al.* 2012).

3.2.2 *The effect of natural environmental variability and human induced climate change*

Rational: At different temporal and spatial scales the marine environment (temperature, salinity, stratification, ocean circulation, etc.) may vary, producing changes in the productivity of the ecosystem, ultimately altering the dynamics of predatory species like tunas, and therefore their fisheries. In addition, climate change is also emerging as a threat to marine ecosystems (Marsac 2017; Erauskin-Extramiana *et al.* 2019). The Standard requires an understanding of climate effects on fish stocks and ecosystems that may be accounted for in fishery management strategy if relevant.

Relevance for purse seine tuna fisheries: This impact may be considered in MSC assessments of purse tuna fisheries as it is well known that natural environmental variability affects the population dynamics of tuna and tuna-like species, and their distributions and biology, while there is increasing evidence of climate change impacts on the physiology, distribution, abundance, and reproductive and feeding migrations of tunas (Dufour *et al.* 2010; Bell *et al.* 2013; Dueri, Bopp & Maury 2014; Marsac 2017; Erauskin-Extramiana *et al.* 2019).

3.2.3 *The ecological impacts of selective fishing*

Rational: Selective fishing (e.g. specific sizes, specific species, specific behaviours) could change (i) the biology and ecology of the species (alter their migration patterns, condition, behaviour), and (ii) the genetic diversity of species resulting for example in genetically determined alteration in demographic parameters (e.g., growth, reproductive output) (Conover & Munch 2002; Hall & Roman 2013).

Relevance for purse seine tuna fisheries: Historically, tunas aggregated around logs and natural debris found in the ocean. Since the 1990s purse seine fisheries have increasingly used man-made dFADs to attract tunas more efficiently. Purse seine fisheries can use either drifting dFADs deployed offshore by more industrial fisheries, or aFADs, which are deployed near shore and to be used by small scale fisheries. The large majority of FADs are dFADs, with about 100,000 estimated to be deployed annually worldwide (Fonteneau, Chassot & Bodin 2013; Scott & Lopez 2014).

dFADs add additional opportunities for species to aggregate in the vast featureless coastal and oceanic waters, by increasing the number of floating objects where natural logs already occur, and by appearing in areas where natural logs would not normally occur. While understanding of why species tend to aggregate floating objects is still limited, several hypotheses have been formulated. It has been suggested that they might provide more opportunities for shelters, or be used as “meeting points” facilitating the formation of larger schools, or be used as feeding opportunities (Dagorn & Fréon 1999; Dagorn *et al.* 2013a).

The increased use of dFADs in purse seine fisheries has raised some concerns as they may change how tuna species and other pelagic species use their habitat. It has been hypothesized that dFADs could alter the natural habitat and the behaviour of pelagic species, and in doing so drive changes in their biology (e.g. growth) and their distributions (Hallier & Gaertner 2008).

It has been observed that dFADs (i) attract tuna from up to 10 kms away , (ii) retain aggregation of species in the vicinity, and (iii) alter the daily vertical behaviour and habitat use of species(Girard, Benhamou & Dagorn 2004; Schaefer & Fuller 2010; Lopez *et al.* 2017; Orue *et al.* 2019).

Tunas are not the only species that aggregate around dFADs. A diverse range of species (fish and non-fish species) are attracted to them. The combined effects of dFADs on the behaviour of tunas and other pelagic species and their increasing use by the purse seine fishery has raised the hypothesis that they may act as "ecological traps" for species as they aggregate biomass of a wide range of species up to several kilometres which would not happen if they were not present (Marsac, Fonteneau & Menard 2000; Hallier & Gaertner 2008).

The ecological impacts of selective fishing via dFAD fishing are considered in MSC assessments of purse tuna fisheries. dFAD fishing has a selectivity pattern for specific sizes of species, specific types of species and specific behaviours. Tunas, especially in the smaller size range, as well as other pelagic species tend to aggregate under the dFADs, and some species are attracted more than others (Hall & Roman 2013). A dFAD fishery may result in competitive disadvantages to some species with genetic and ecological implications (Hall & Roman 2013).

3.2.4 *The ecological impacts of introducing marine debris.*

Rational: ALDFG can generate four different types of ecosystem impacts (Gilman 2015; Zudaire *et al.* 2019): (i) the entanglement of vulnerable non-target species such as seabirds, turtles and shark on ALDFG, or by its ingestion, resulting in an increased mortality of those species, (ii) impacts on vulnerable habitats, (iii) the production of microplastics due to the breakdown of plastic materials, leading to the release of toxics substances that may be introduced into the food chain. This may suppose a threat to the human health and the ecosystem, and (iv) the litter generated by a fishing boat if dumped overboard may introduce waste into the marine ecosystem impacting habitats.

Relevance for purse seine tuna fisheries: The four potential impacts of ALDFG may be a subject of consideration in the MSC assessments of purse tuna fisheries, particularly those using dFADs, since they can generate ALDFC in large quantities. Yet only the impacts of ALDFG via the introduction of toxics substances and microplastics throughout the food chains with potential consequences to human health may be a subject of consideration in the MSC assessments under C.5.

3.3 General guidelines to facilitate the assessment of ecosystem impacts under C2.5

As noted previously, the evaluation of ecosystem impacts only considers the UoA. Each type of ecosystem impact may require the monitoring of different attributes of the ecosystem e.g., the ecosystem impact of removing top predatory species could alter different elements or attributes of the ecosystem (the trophic relationships in food web or the size structure of ecological communities).

A four-step basic guideline facilitates assessment of the main types of ecosystem impacts that may be considered when assessing tuna purse seine fisheries (Figure 2).

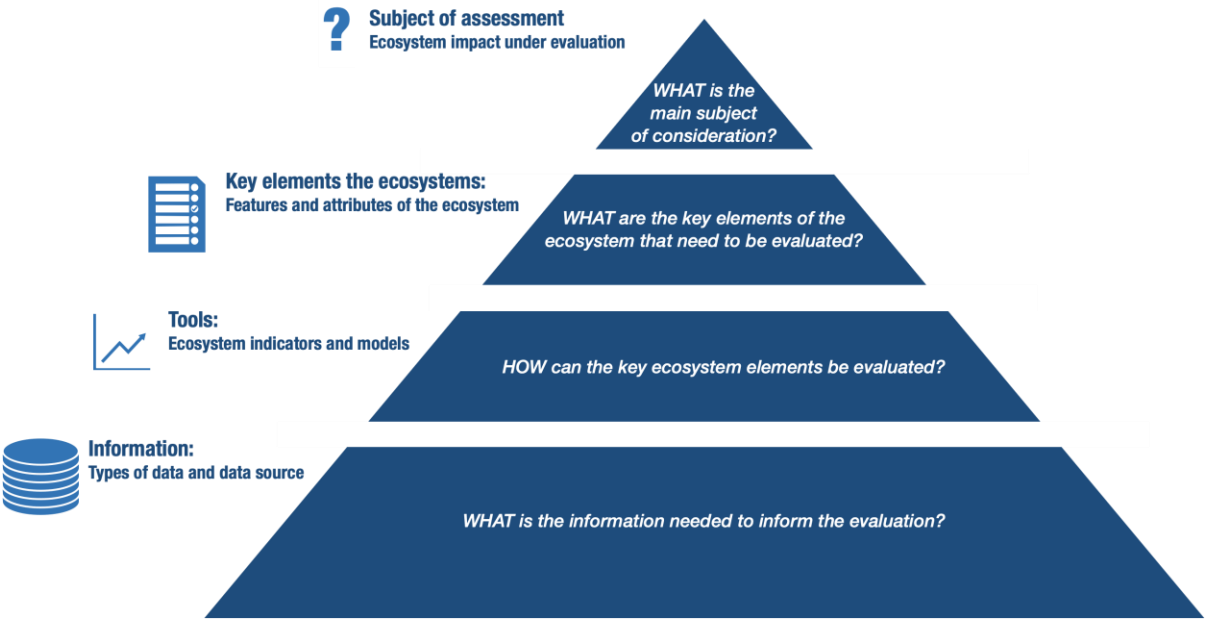

Figure 2: A four-step basic guideline that an auditor may consider in when auditing C2.5

- **What is the main subject of consideration?** The first step consists in identifying and describing a priori the type of ecosystem impact that may be evaluated under C2.5. Section 2.3 describes the main types of ecosystem impacts relevant to purse seine fisheries.
- **What are the key elements of the ecosystem that need to be evaluated?** The second step consists of identifying what ecosystem elements and attributes may need to be monitored to assess ecosystem impacts. Different ecosystem elements or attributes may need to be assessed and monitored for each of the defined main types of ecosystem impact. Table 2 lists the main type of ecosystem impacts and what may be the potential key features and attributes of the ecosystem to be understood and monitored in any C2.5 assessment of purse seine fisheries.
- **How can the key ecosystem elements be evaluated?** The third step consists in identifying the tools and the type of ecosystem indicators (and ecosystem models) that may be needed to monitor key ecosystems attributes to evaluate each of the ecosystem impacts (Figure 2). Each ecosystem attribute being assessed may require different tools and indicators to assess impacts in any C2.5 assessment. Table 3 presents a list of key elements or attributes of the ecosystem and associated ecosystem indicators that could be estimated (or are commonly estimated) to capture and monitor changes in the

Table 2: Main type of ecosystem impacts (EI) and key elements of the ecosystems to be evaluated.

Main subject of consideration	Key elements of the ecosystem to be evaluated
EI 1. The ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of marine ecosystem	• Biomass of ecological community • Trophodynamics of ecological community • Fishing Pressure on the ecosystem
EI 2. The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the truncation of size composition on the structure and function of marine ecosystem.	• Biomass of ecological community • Size structure of ecological community • Age structure of ecological community
EI 3. The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the alteration of diversity on the structure and function of marine ecosystem.	• Biomass of ecological community • Diversity of ecological community
EI 4. The effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and tuna dynamics.	• Physical and biological properties of water column, for example temperature, salinity, chlorophyl-a, oxygen, stratification
EI 5. The effects of climate change on ecosystem productivity and tuna dynamics.	• Climate scenarios of temperature, salinity, chlorophyl-a, oxygen, stratification
EI 6. The ecological impact of FAD use via selective fishing on the genetic, biology and ecology of tunas (target catch) - dFADs as ecological traps.	• Genetic diversity of species • Biology of species (condition, growth, reproduction) • Ecology of species (migration, behaviour, reproduction)
EI 7. The ecological impact of FAD use via selective fishing on the genetic, biology and ecology of non-tunas (non-target catch) - dFADs as ecological traps.	• Genetic diversity of species • Biology of species (condition, growth, reproduction) • Ecology of species (migration, behaviour)
EI 8. The ecological impact of fishing via the introduction of microplastic pollution into the food web.	• Microplastic in fish

Table 3: Main key elements or attributes of the ecosystems to be understood and monitored to evaluate the type of ecosystem impact, and potential indicators that could be used to better understand the key elements of the ecosystems and inform evaluations.

Key elements of the ecosystem	Indicator type	Brief description and rationale	Potential data types and sources
Fishing Pressure on the ecosystem (also used as proxy of community abundance changes)	**Community-level pressure indicators e.g.:** • Catch rates • Discards rates or proportion of discards in the fishery (discards/landings)	Logbook records with total catches and effort for commercially valuable species are widely reported. In addition, a portion of the fisheries may carry observers. From these, catch-per-unit-of-effort (CPUE) over time can be estimated, at least for the most common species, to monitor changes in catch rates. CPUE indicators are commonly used as an indicator of stock health in single species fishery assessments, but they can also be used to monitor community-level changes in CPUE. They are not easy to obtain as they depend on the quality of the fishery data sets (Fulton *et al.* 2004) Community and population-level discards rates can be used to monitor landings *cf* catch. It is used to provide insights about the pressures on the entire community exposed to fishing and it is important for them to be estimated at the fishery levels as each fishery and gear type can have different discard rates and therefore distinct ecological effects. These indicators rely on fisheries dependent data, and their interpretation can be masked by a wide range of confounding factors (changes in gear type, targeting and effort) (Fulton *et al.* 2004).	• Empirically estimated using fisheries dependent data • Model-derived
Environmental Pressure on the ecosystem (including climate change)	**Climate indicators e.g.:** • Southern Oscillation Index (SOI) • Equatorial SOI • IO Dipole **Physical surface conditions e.g.:** • Sea surface temperature • Sea surface height	Environmental gradients and fronts of essential abiotic (temperature, dissolved oxygen, currents) and biotic (ocean color, plankton and micronekton aggregations) factors play a key role in tuna movement and distributions. Life history traits, population growth rates, movements and stock abundance are influenced by factors other than fishing. Climate and environment indicators can also be used to understand past trends in catches and to improve the quality of forecasts, thus contributing to more accurate management advice (Gilman *et al.* 2016; Marsac 2017; Marsac & Shahifar 2019).	• Climate Diagnostics Bulletin, Climate Prediction Centre of the NOAA, USA • *In situ*, satellite and model- derived • World Ocean Atlas • Models (i.e. GODAS, CMEMS)

	• Ocean surface stress **Physical sub-surface conditions e.g.:** • Mixed layer depth • Thermocline depth **Biogeochemical and biological indicators e.g.:** • Dissolved oxygen • Ocean acidification		• Biogeochemical models (e.g. PISCES, CMEMS)
Biomass of ecological community	**Species level biomass indicators e.g.:** • Species or population-level biomass **Community level biomass-based indicators e.g.:** • Total biomass of the community • Biomass by taxa groups or trophic based or size-based groups.	Community-level or population level biomass indicators are commonly used to assess the impact of fisheries on ecosystem and track the state of key functional groups in the system. They are easy to understand but also subject to natural environmental variation. Direct independent measures are not available to derive them. Stock-assessment models and ecosystem models (trophic based or size based) are required to obtain estimates of abundance and biomass for different taxa and trophic-based or size-based groups.	• Model-derived
Size structure of ecological community	**Community level size-based indicators e.g.:** • Mean size of predefined groups from catch data or biomass estimates. • 95% percentile (or others) of the size distribution of	Size data is the most commonly and easily collected type of fishery data. Aside from supporting the fisheries assessments at the population level, it can also serve to assess changes in size structure at the community and ecosystem level. Fish size generally decreases under fishing pressure as high-value target species are generally lager, fishing gears are also size-selective often designed to target the larger fish, and larger fish also tend to be more vulnerable to fishing because of their life history traits (Shin *et al.* 2010a).	• Empirically estimated using fishery dependent data • Model-derived

	predefined groups from catch data or biomass estimates. • Proportion of large fish (proportion of fish catches or fish biomass larger than a specific size value) • The slope and intercept of the biomass size spectra of the marine community	These size-based indicators can be derived using catch data or biomass estimates from ecosystem models. In the case of the biomass size spectra, this indicator may only be estimated from size-based ecosystem models (Shin *et al.* 2005). While biomass size spectra indicators are commonly estimated using data from independent-surveys they are not available for open-ocean ecosystems.	
Age structure of ecological community	**Community level age-based indicators e.g.:** • Average age of predefined groups from catch data or biomass estimates. • 95% percentile (or others) of the age distribution of predefined groups from catch data or biomass estimates. • Proportion of older fish (proportion of fish catches or fish biomass larger than a specific age value).	The greater reliability of aging techniques has increased the number and use of age-based indicators. The means and tails of age distributions data at the species and community level can be informative about fishing effects as fisheries usually target larger and older individuals. The collection and estimation of age structure data remains more costly than collecting size data. Aside from supporting fisheries assessments at the population level, age data can also assess the changes in age structure at the community and ecosystem level(Fulton *et al.* 2004) These indicators can be derived using catch data or biomass estimates from ecosystem models	• Empirically estimated using fisheries dependent data • Model-derived
Trophodynamics of ecological community	**Trophic-based indicators e.g.:** • Mean trophic level of the catch by fisheries. • Mean Trophic Index (the same as the mean trophic level of catches but includes	Trophic-based indicators have been used to identify shifts in community and ecosystem structure. There are multiple forms and variations of these indicators and depending on the way they are estimated (based on catches, or the estimates of biomass from models) different interpretations and uses can be made. In general terms, they allow monitoring of species composition (in the catch or in the ecosystem) in terms of trophic positioning(Shannon *et al.* 2014a).	• Empirically estimated using fisheries dependent data • Model-derived

	only catches of species with trophic levels above 4) • Mean trophic level of the community (derived with biomass estimates from ecosystem models). • Proportion of predatory fishes in the ecosystem • Fishing in Balance (FIB) index. It relates the catches and the average trophic level in a given year to the catches and trophic level of an initial year, and the determines if the change in the mean trophic level is compatible with the trophic efficiency of the region.	The mean trophic level when derived using catch data from the fisheries (Pauly & Watson 2005) can be a useful metric to monitor ecosystem change. Generally, it is expected to decrease in response to fishing because fisheries tend to target species at higher trophic levels first. But other patterns (increases in the trophic level of catches) have also been observed, and therefore this indicator can also provide information on the changes of fishing and targeting practices in response to changes in fish abundances or market drivers. The mean trophic level of the community-level biomass can be derived with the biomass estimates from ecosystem models(Shannon *et al.* 2014a). This indicator can be used to monitor the mean trophic level of different functional groups in the ecosystem (categorized in different trophic levels ranges, e.g., trophic level 3.0-3.25, 3.25-5, >4), and allows to identify changes in the ecosystem structure after the biomass removals from fisheries. These model-derived indicators across different trophic level groups can be used in combination to detect trophic cascades. The proportion of predatory fish measured as the estimated biomass of predatory functional groups is also used to monitor the potential effects of fishing on the functioning of marine food webs as their depletion can lead to trophic cascades(Shin *et al.* 2010b). The FIB index provides an indication whether fisheries are balance in ecological terms and not causing disruption to the functionality of the ecosystem(Pauly, Christensen & Walters 2000). A constant FIB (equal to zero) means that a fishery is balanced where all trophic level changes are matched by ecological equivalent changes in the catches. FIB <0 indicates that the effects of fishing, by the removal of excessive levels of biomass, are sufficient to compromise the functionality of the system, and a FIB >0 indicates either a bottom-up effect (e.g. increase in primary productivity) or an expansion of the fishery (increase in the diversity of species caught and or biomass of bycatch species) (Kleisner & Pauly 2011; Pauly & Lam 2016).	

		All trophic based indicators rely heavily on diet analysis and modelling to determine the trophic level of the species. The collection of diet data can be expensive, and it is not collected as frequently as the catch or biomass data.	
Diversity of ecological community	**Diversity based indicators e.g.:** • Shannon's index • Kempton's Q index adapted for ecosystem models	Diversity-based indicators that monitor fishing impacts at the community and ecosystem levels might be difficult to be applied as they are highly susceptible to sampling problems. Simple biodiversity indicators are preferred e.g., the Shannon index is widely used as a measure of species diversity based on species richness and the relative proportions of species in a community (evenness), generally measures in terms of biomass(Shannon 1948). A decrease in the index indicates reduced evenness and richness. Kempton's Q index adapted for ecosystem models is a diversity-based index for assessing changes in the diversity and biomass of high trophic level species (trophic level >3)(Ainsworth & Pitcher 2006). A decrease in the index indicates reduced upper-level evenness and richness.	• Empirically estimated using fisheries dependent data • Model-derived
Genetic diversity of species **Biology of species (condition, growth, reproduction)** **Ecology of species (migration, behaviour)**	**Indicators before and after FAD use e.g.:** • Indicators of genetic diversity • Condition of species, including growth rates and reproductive output. • Distribution and movements	dFAD fishing has a selectivity pattern for specific sizes of species, specific behaviour and types of species. Selecting fishing could change (i) the biology and ecology of the species (alter their migration patterns, condition, behaviour), and (ii) the genetic diversity of species resulting e.g., in genetically determined change in demographic parameters (e.g., growth, reproductive output).	•Experimental studies to evaluate the impacts of dFAD use on the biology and ecology of species attracted to dFADs

ecosystem attributes. Each type of indicator comes with a reference to the type of attribute it tries to capture and describe of the ecosystem.

- **What is the information needed to inform the evaluation?** The four step consists in identifying the type of data, and their source, needed to develop the indicators and ecosystem models (and support research in general) that are used to monitor changes in ecosystem attributes and inform the evaluation of impacts (Figure 2). Table 3 lists potential data types and sources that may be relevant to conduct the assessment of ecosystem impacts.

There has been extensive research on ecosystem indicators with multiple ecosystem indicators identified, developed, tested and put forward to monitor the effects of fishing on marine ecosystems (Fulton, Smith & Punt 2005; Shin *et al.* 2010a; Coll *et al.* 2016b). These are used to describe and capture changes in multiple attributes of the ecosystem including, biomass, size structure, spatial structure, diversity, trophic level, and energy flows. Attributes are features of the ecosystem that society might be interested to capture and protect and are usually linked to common ecosystem level objectives such as maintaining ecosystem health, integrity or resilience (Fulton *et al.* 2004; Fulton, Smith & Punt 2005).

It is also widely recognized that no single or type of indicator can provide a complete picture of the ecosystem state. The natural complexities of marine ecosystem and ecological process requires the use of a suite of indicators to provide a complete picture of the impacts of fishing on the ecosystem that: (i) monitor and highlight changes in the system structure, (ii) help to diagnose the causes of those changes in the system, and (iii) monitor the recovery of lost properties in the system (Fulton *et al.* 2004).

When considering the potential to develop the indicators for data sources, it is important to distinguish between whether an indicator can be empirically estimated using regularly collected fisheries dependent data (e.g., logbooks, observer programs), or if it needs to be derived from ecosystem models (e.g., trophic based models or size-based models). Most ecosystem indicators (Table 3) can mainly be estimated using these two sources.

In general, in the high seas where most tuna fisheries operate, independent fisheries data obtained from biological surveys (a common source of data in most coastal ecosystems) is not available. This is a major impediment to robust analysis of the current state of the fisheries and ecosystem (National Research Council 2006). However, fisheries dependent data is generally more readily available to support the developing and testing of ecosystem indicators, while computer simulations and ecosystem models also provide an alternative tool to study the system and derive model-derived ecosystem indicators to understand the properties of the ecosystem and its responses to fishing pressure (Fulton *et al.* 2004).

However, fishery dependent data complemented with data derived from dedicated research studies (e.g., trophic ecology of species) remains the main source of data to feed ecosystem models for the open ocean. Therefore, any ecosystem study or analysis using fishery-dependent data can be subject to various interpretations since fisheries can change their fishing location and target species in response to many factors other than the abundance of fish species (e.g., markets, management, technology etc.).

4. THE ASSESSMENT OF C2.5 IN OTHER MSC FISHERIES

4.1 Approach

Review of 13 MSC assessments (final reports and client draft reports (CDR)) of purse seine fisheries targeting tropical tuna species (skipjack, yellowfin and bigeye tunas) setting on free schools and dFADs

allows examination of the scoring rationales for C2.5 (Table 4). Most of these comprise FSC & dFADs, but some only assessed the former.

In reviewing the various assessments, (i) the types of ecosystem impact and the key elements were identified; and (ii) the scoring rationales for PI 2.5.1, 2.5.2 and 2.5.3 were reviewed.

4.2 Findings

Comparative analysis of the approach of the various fisheries is shown in Table 5.

- All evaluated the ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of marine ecosystem. In doing so, they focused on evaluating if predator removals, especially keystone species, altered the trophic relationships in the marine food web resulting in trophic cascades which could disrupt the overall balance of the ecosystems.
- None considered the potential impacts of fishery removals of top predators via the truncation of size composition and the alteration of biodiversity on the structure and function of marine ecosystem. While one mentioned the importance of understanding fishing impacts on biodiversity, the point was not considered in the scoring rational. In part this was due to most ecosystem models being developed to understand the impacts of tuna fisheries on oceanic ecosystems are trophic based, with few attempts to develop size-based ecosystem models. Similarly, the use of size-based community indicators has not been common to monitor ecological impacts of fishing in oceanic fisheries.
- The effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and the dynamics of predatory tunas has been a key subject of consideration in assessments. Five of the assessments formally assessed these effects and included them in the scoring rational. Six of the assessments noted the effect as being important but did not formally consider it in the scoring rationales.
- Some of the assessments evaluated the impact of the UoA on the oceanographic processes of the area and justified the scoring around this interaction. This is not considered a good practice. Instead the relevant ecosystem interaction is whether the effect of large scale climatic and oceanographic physical forcing (natural environmental variability) has any effect on ecosystem productivity, which ultimately may impact the dynamics of predatory tunas and the fisheries management.
- Three of the assessments considered the effects of climate change on ecosystem productivity and tunas, while two noted it as an important subject.
- Two (AGAC WCPO and EPO) did not assess the ecological impact of dFAD use via selective fishing on the genetic, biology and ecology of tunas (the target species).
- Two of the assessments considered the ecological impact of FAD use via selective fishing on the genetic, biology and ecology of non-tunas (non-target catches such as sharks).
- None of the assessments considered the ecological impact of fishing via the introduction of microplastic pollution from fishing gear into the food web.

Table 4. MSC assessments reviewed.

Fishery	Code	UoA	Source	Fishery	Code	UoA	Source
Echebastar IO Skipjack Tuna Purse Seine Fishery	ECHEB IO	SKJ -IO- PS dFADs and FSC	FR 11/ 2018	PNG Fishing Industry Association's purse seine Skipjack & Yellowfin Tuna Fishery	PNG PSF WCPO	SKJ YFT -Papua New Guinea Pacific Ocean - PS dFADs, aFADs and FSC	FR 4/2020
CFTO IO Purse Seine Skipjack fishery	CFTO IO	SKJ -IO- PS dFADs and FSC	CDR 12/ 2019	Micronesia Skipjack, Yellowfin and Bigeye Tuna Purse Seine Fishery	MICRO PSF WCPO	SKJ YFT BET -Micronesia Pacific Ocean - PS dFADs and FSC	CDR 8/2020
AGAC four oceans Integral Purse Seine Tropical Tuna Fishery (Indian Ocean)	AGAC IO	SKJ YFT BET -IO- PS dFADs and FSC	CDR 2020	Tropical Pacific yellowfin and skipjack tuna free-school purse seine fishery	TP PSF WCPO	SKJ YFT -WC Pacific Ocean - PS FSC	PCR 10/2019
AGAC four oceans Integral Purse Seine Tropical Tuna Fishery (Atlantic Ocean)	AGAC AO	SKJ YFT BET -Atlantic Ocean - PS dFADs and FSC		ANABAV Atlantic unassociated purse seine yellowfin tuna fishery	ANABAC EAO	YFT - Eastern Tropical Atlantic Ocean - PS FSC	CDR 6/2020
AGAC four oceans Integral Purse Seine Tropical Tuna Fishery (Western and Central Pacific Ocean)	AGAC WCPO	SKJ YFT BET -WC Pacific Ocean - PS dFADs and FSC		Eastern Pacific Ocean tropical tuna - purse seine (TUNACONS) fishery	TUNACONS EPO	SKJ YFT BET -E Pacific Ocean - PS dFADs and FSC	CDR September 2020
AGAC four oceans Integral Purse Seine Tropical Tuna Fishery (Eastern Pacific Ocean)	AGAC EPO	SKJ YFT BET -E Pacific Ocean - PS dFADs and FSC		The North-eastern Tropical Pacific Purse Seine Yellowfin and Skipjack Fishery	NETP PSF NE PO	SKJ YFT -NE Pacific Ocean - PS FSC and dolphin-free	FR 2015
Eastern Pacific Yellowfin and Skipjack Tuna Purse Seine	EP YFT SKJ PS	SKJ - YFT	CDR 2020				

Table 5 Comparative analysis of MSC CDR /final reports of P2.5. Type of ecosystem impacts and whether these were formally considered (Y) or not considered (N) when building the rational to justify scoring against PI 2.5.1, 2.5.2 and 2.5.3 across the 13 fisheries being reviewed (columns). In some cases the ecological impact was mentioned in the assessment but not formally assessed in scoring rationales (NFA) (NA = Not applicable).

TYPE OF ECOSYSTEM IMPACTS	ECHEB IO	CFTO IO	AGAC IO	AGAC AO	AGAC WCPO	AGAC EPO	EP YFT SKJ PS	PNG PSF WCPO	MICRO PSF WCPO	TP PSF WCPO	ANAB AC EAO	TUNAC ONS EPO	NETP PSF NE PO
The ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure and function of marine ecosystem	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the truncation of size composition on the structure and function of marine ecosystem.	N	N	N	N	N	N	N	N	N	N	N	N	N
The ecological impacts of fishery removals of species (either top predators or other species in the foodweb) via the alteration of diversity on the structure and function of marine ecosystem.	N	N	N	N	N	N	N	N	N	N	NFA	N	N
The effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and tuna dynamics	NFA	N	NFA	NFA	Y	Y	N	Y	NFA	Y	NFA	NFA	Y
The effects of climate change on ecosystem productivity and tuna dynamics	NFA	N	N	N	N	Y	N	N	N	Y	N	N	Y
The ecological impact of FAD use via selective fishing on the genetic, biology and ecology of tunas (target catch) - dFADs as ecological traps	Y	Y	Y	Y	N	N	Y	Y	Y	NA	NA	Y	NA
The ecological impact of FAD use via selective fishing on the genetic, biology and ecology of non-tunas (non target catch) - dFADs as ecological traps	NFA	N	N	N	N	N	Y	Y	N	NA	NA	N	NA
The ecological impact of fishing via the introduction of microplastic pollution into the food web	N	N	N	N	N	N	N	N	N	N	N	N	N

5. RESEARCH INTO THE POTENTIAL IMPACTS OF PURSE SEINE TUNA FISHERIES ON KEY ELEMENTS OF THE ECOSYTEM

5.1 Approach

The previous section identified the main types of ecosystem impacts that may be considered under P2.5 in purse seine tuna fishery assessments, and those key ecosystem elements or ecosystem attributes that need to be understood and monitored to evaluate each of the types of ecosystem impact.

Section 5 focuses on gathering and summarizing past and on-going research into the potential for ecosystem impacts from purse seine fisheries (FSC and dFADs).

To describe ecosystem impact from purse seine fisheries and analysing the current scientific evidence, the following four potential impacts are considered:

- The ecological impacts of fishery removals of top predators on the structure and function of the marine ecosystem.
- The effect of natural environmental variability (including climate change) on ecosystem productivity and tuna dynamics.
- The ecological impacts of FAD use on the genetic, biology and ecology of species (tunas and non-tunas).
- The ecological impacts of marine debris via the introduction of toxic substances and microplastics on the ecosystem

In addition, it is also considered whether purse seine fisheries (i) have adequate information and detailed study, and (ii) where the impacts of purse seine fisheries have not been investigated in detail and are poorly understood.

5.2 Main ecosystem impact from purse seine fisheries: Information and research

5.2.1 *The ecological impacts of fishery removals of top predators on the structure and function of marine ecosystem*

There is increasing evidence that the abundance and composition of targeted and non-targeted species is changing because of fishing.

Fishing may have ecosystem effects; the magnitude of which will depend on the quantity of fishery removals and the functional role of the removed species (Polacheck 2006). Depletion of predators, especially keystone ones, could (i) cause trophic cascades due to changes in predatory-pray interactions and trophic relationships to the extent that the overall balance of the ecosystem could be disrupted, (ii) severely truncate the size composition of the ecological community and slow the recovery of species, and (iii) create gross changes in species diversity of the ecological community (e.g., loss of species, major changes in species evenness and dominance) to the extent that the overall balance of the ecosystem could be disrupted.

In some cases, fishing has led to alternative ecosystem states with varied species composition or productivity relative to the pre-fishing condition. A classic example of large-scale system changes is the overexploitation and depletion of cod as well as other high trophic levels species in the Northwest Atlantic, which led to a drastic restructuring of the entire food web, attributed in part to trophic cascades by the removal of top predators (Frank *et al.* 2005).

Purse tuna fisheries capture top predatory species of assorted sizes, trophic levels, and quantities. The actual ecological impact will depend on the quantity of the species removed, the size structure of the species removed, and the composition and biological characteristics of the species removed.

A growing body of literature evidence the impacts of industrial tuna fishing on the structure and function of marine ecosystems (Cox *et al.* 2002; Polovina & Woodworth-Jefcoats 2013; Griffiths *et al.* 2019), although assessing the impact of fishing on the broader structure and function of marine ecosystems in the open ocean remains difficult.

There are also significant difficulties in understanding the relative impacts of the total removals of biomass from the different fisheries and gears operating in a defined area, and detecting changes in the relative abundance of species and reliable assigning those changes to specific fisheries and gears (Allain V., Griffiths & S. 2015).

In open-ocean ecosystems multispecies and ecosystem models are emerging as effective tools in understanding the impacts of multiple gears and multiple harvest strategies on the structure and dynamics of marine ecosystems and to compare the possible outcomes of different fishery management options (National Research Council 2006; Griffiths *et al.* 2019). Increasingly trophic based and size based ecosystem models are being used to explore specific hypothesis that allow representation of the complex ecological interaction and trophic (feeding) relationships or size based relationships across a wide range of species in the ecosystem and their interactions with different fishing gears (and harvest strategies) and other external factors such as environmental variability and climate change (Polovina & Woodworth-Jefcoats 2013; Allain V., Griffiths & S. 2015).

In the open ocean, ecosystem models have been useful for exploring the consequences of alternative fisheries management scenarios on economically important species, and to understand how fishing impacts may propagate to other species through the wider pelagic ecosystem.

Ecosystem research and the development and use of ecosystem models to explore the consequences of alternative fisheries management and environmental scenarios on economically important species and the wider pelagic ecosystem vary greatly by ocean and tuna RFMOs.

In the EPO and WPO, several trophic-based ecosystem models (using Ecopath with Ecosim (EwE) modelling) have been developed to understand the ecosystem level changes from tuna fisheries and the environment in general (Olson & Watters 2003; Allain V., Griffiths & S. 2015; Griffiths & Fuller 2019; Griffiths *et al.* 2019). A series of ecological indicators mostly trophic-based and diversity-based indicators (e.g., mean trophic level of the catch, mean trophic level of the modelled community, fishing in balance index) are also routinely monitored over time to evaluate changes in the ecosystem structure after biomass removals by fishing, and detect potential trophic cascades. Such modelling suggests that since the 1980s the ecosystem structure has changed significantly due to the harvest of top predators. These studies went a step further and explored the potential ecological impacts of decades of industrial fisheries on the ecosystem structure and the biomass of individual species (targeted, non-targeted species) and the plausible ecological impacts of future alternative efforts regimes with a focus on exploring alternative FAD efforts (hypothetical increasing and decreasing FAD efforts) in purse seine fisheries (Griffiths & Fuller 2019; Griffiths *et al.* 2019).

In the WPO, ecosystem modelling and simulations with a reduction of dFAD effort by at least 50%, predicted an increase in the biomass of tuna species including bigeye tuna, and vulnerable sharks and a recovery of ecosystem structure to a pre-industrial fishing state within 10 years (Griffiths *et al.* 2019). In contrast, simulations with an increase in 100% FAD effort from current levels between 2016 and 2046 suggested that it is an unlikely viable measure. The 100% increase in FAD effort translated in a decrease in the sustainability of the tuna species directly targeted (yellowfin and bigeye tunas), and a decrease in the sustainability of the vulnerable-long-lived bycatch species (silky, oceanic whitetip, and mako sharks), whose biomass were predicted to decline by 43%, 26.1%, 24.1%. respectively. Yet, the simulated 100% increase in the FAD effort also resulted in increased up to 15% the biomasses of FAD-associated species such as wahoo, mahi-mahi, and rainbow runner, which is a trophic response from reducing their natural predators.

From an ecosystem perspective, the simulations carried out in Griffiths et al., 2019 in the WPO did not predict a substantial change in the structure and function of the marine ecosystem or any substantial trophic cascades after decades of industrial fishing. Furthermore, the simulations also showed that the ecosystem structure appeared to be resilient to the simulated fishing perturbations and to the substantial changes in biomass of many of the high-trophic level target and bycatch species. This resilience appeared to be driven by the high diversity of highly productive fishes in the upper trophic levels in oceanic waters that are generally opportunistic predators and consume a wide variety of prey (Griffiths *et al.* 2019).

Under these circumstances, trophic cascades are harder to follow, since biomass declines from the targeted species are quickly buffered by small changes in biomass in a wide range of opportunistic predators. This indicates that the high-trophic level species (targeted and non-targeted) species only exert a weak tow-down regulation.

Griffith *et al*. 2019 recommended that the combined fishing efforts from the three major gears (purse seine, longline and pole and line) in this region need to be monitored in combination (not in isolation) and ensure that if they increase, they do not eventually drive the ecosystem to a tipping point of no return where the altered ecosystem dynamics could no longer be reversed by any level of management intervention.

While the Griffith *et al.* 2019 study focused the simulations on increases and reductions of FAD efforts, future studies would benefit from simulating effort scenarios for the long line fisheries and their interactions with the other gears (purse seine, and pole and line) to explore potential harvest strategies to assist managers in exploring trade-offs and finding optimal economic and ecological outcomes on which to base their management decisions.

In the EPO**,** ecosystem modelling and its derived trophic-based ecological indicators also suggest a significant change in ecosystem structure over the last 50 years from the exploitation of top predators such as tunas, billfishes and sharks (Griffiths & Fuller 2019). The biomasses of high trophic level species (above trophic level 4) declined steadily from the 1970s to 2014. Furthermore, as a response to lowering predation pressure on the lower trophic levels, there has also been a steady increase in the community biomass of the trophic levels less than 4. Simulations with an increase of dFAD effort predicted a further reduction on the biomass of all target tuna species (yellowfin, bigeye and skipjack tuna) and other vulnerable bycatch species (sharks and rays), while simulation with a decrease of dFAD effort predicted an increase in biomass for the target tunas, but not for the larger bigeye tuna, which predicted a decline. These scenarios which are considered preliminary, as the result may be due to the impact of longline effort on bigeye tuna in the area which has also been increasing in the region (Griffiths & Fuller 2019).

Simulations also suggest that a substantial reduction in purse-seine effort, but also longline effort, is required to restore the ecosystem structure back to 2010 level when the combined effort of purse and longline was around half of what it is today. However, this study also suggested that the patterns observed are not considered detrimental to the structure and function of the ecosystems, but that these changes warrant continued monitoring.

The advances in ecosystem modelling in the PO (WCPFC and IATTC) are the result of decades of region-specific biological, ecological and fisheries research data which are now being used to build ecosystem models to examine the impacts of fisheries and multiple harvest strategies on the structure and dynamics of marine ecosystems. The existing ecosystem models have been supported by a combination of high-quality stock assessment model data for many of the targeted and bycatch species, reliable catch time series for non-targeted species and reliable estimates for forage species and large phytoplankton. The regionally coordinated observer programmes to monitor catches (and discards) for a wide range of species caught in the WCPFC and IATTC pelagic fisheries (at least for some

of their fisheries) have also been crucial to inform these ecosystem models. All the fisheries included in the ecosystem models developed in the PO have relatively good estimates of the annual landings and to some extent discards for the most important species, usually derived from vessel logbook, and validated or estimated using the regionally coordinated scientific observer data collected.

The Pacific Ocean has a relatively robust history of trophic level studies to construct the diet matrix to establish the trophic linkages for all predatory-prey interactions or functional groups established in the models. Studies on the trophic ecology of predatory fishes (using stomach content and stable isotope analysis), which have formed the basis for representing food-web interactions in an ecosystem model, and the development of ecosystem modelling, have been active research topics in the WCPFC and IATTC for the past 20-30 years, and these tools are being used to explore the ecological impacts of fishing and climate change in these regions and provide fisheries management advice (Griffiths & Fuller 2019; Griffiths *et al.* 2019; IATTC 2019).

The state of research in the WPO and EPO allows the conclusion that after 50-60 years of industrial fishing, the removal of top predators has not been detrimental to the structure and function of the eastern and western equatorial ecosystem to the point where there would be a serious or irreversible hard, but the scientific community recommends that the situation be monitored (Griffiths & Fuller 2019; Griffiths *et al.* 2019).

In comparison, research activities on diet analysis, trophic relationships, food-web analysis, and the development of ecosystem models and indicators to track ecosystem changes in response to fishing and the environment have been more limited in the equatorial AO and IO.

Research on the trophic ecology of pelagic fishes in the IO needs to provide the detail that exists for the Pacific Ocean the IOTC should consider a more comprehensive approach, combining stomach contents data, trophic tracers such as stable isotopic analysis and genetic studies to get a better understanding of the trophic pathways that support commercially important IOTC species, and provide the trophic knowledge to support the development of ecosystem studies (Olson *et al.* 2016).

There is a critical need to conduct trophic studies for not only the commercially important IOTC species (mostly tunas and billfishes) but also on other species such as sharks, neritic tuna species, and their prey.

None of the community- and ecosystem-level indicators presented in Table 3 are routinely estimated and monitored by ICCAT or IOTC. Although some of the indicators presented in Table 3 may be under development in the ICCAT Subcommittee on Ecosystems and IOTC Working Party on Ecosystems and Bycatch (WPEB), as these scientific working groups have recently started to develop an ecosystem report card for the ICCAT and IOTC regions (Juan-Jordá *et al.* 2017b; Juan-Jordá, Murua & Andonegi 2018).

For example, European scientists (IEO, AZTI, IRD) are using the available data (logbook fisheries data and observer data) from the European purse seine fishery catching tropical tunas in the AO and IO to examine the potential ecological effects of this fishery on the structure and function of the tropical marine ecosystem (Andonegi *et al.* 2019; Juan-Jordá *et al.* 2019a). This work, under development, aims to compare the total biomass removed by the fishery in terms of weight, trophic level and replacement time among each purse seine fishing method (sets on dFADs and FSC). These indicators collectively seek to understand the ecological effects of removing all species through fishing, not only the bycatch or discards. In addition to monitoring of the total biomass removed, they also monitor changes in the species composition of the total catch (whether they are retained or not), and use information of the life histories of species and their ecological role in the foodweb to understand fishing impacts.

While there has been some work developing empirical ecosystem indicators (using fisheries dependent data) in the equatorial AO and IO, the development and use of ecosystem models as an additional tool for informing on the state of the ecosystem and potential fisheries management strategies in IOTC and ICCAT has been limited. A few attempts have been made to develop ecosystem models but they are considered preliminary and they have not been used to generate indicators for tracking ecosystem changes and provide ecosystem-based advice for fisheries management (Forrestal 2016; Juan-Jordá *et al.* 2017a).

The increasing use of these tools in the other tuna RFMOs (e.g., WCPFC and IATTC) may serve as an example to incentivise this type of modelling work and further development of ecosystem models in the AO and IO. Until then, the lack of ecosystem modelling, or even the lack of more simple empirical ecological indicators that could be derived using the observer programs, hinders any attempts to evaluate the impacts of fishery removals of top predatory species such as tropical tunas in the AO and IO.

The lack of baseline research limits understanding of (i) the potential consequences of removals of top predators in the ecosystems, (ii) the likely changes to mid-trophic level species abundances (iii) changes to mean trophic level of the communities, and (iv) other potential impacts, and evaluate if the structure and function is being altered to the point of serious or irreversible harm.

5.2.2 *The effect of natural environmental variability and human induced climate change on ecosystem productivity and tuna dynamics*

At different temporal and spatial scales, changes in the marine environment (temperature, salinity, stratification, ocean circulation, climate regimes, etc.) may impact productivity of the ecosystem and this may alter the dynamics of predatory tunas and tuna-like species (Marsac 2017). As mentioned before, recognizing the increasing importance of climate change the Standard requires consideration of the effects of environmental change on the natural productivity of the UoA that may be considered by fishery managers.

The main circulation patterns and hydrological features of all the tropical oceans are well known, as well as climate variability at different temporal scales (decadal, annual, seasonal, intra-seasonal, and short-term). The physical and biological data to describe the environmental dynamics in each ocean region is generally available and accessible (remote sensing data, ocean circulation models, word ocean atlas, Table 3).

The same patterns and features have been identified in the IO (Schott & McCreary 2001; Schott, Xie & McCreary 2009; Kaplan *et al.* 2014; Marsac 2017; Hermes *et al.* 2019). However, the most relevant aspect is to understand how the natural environmental variability in a region affects the population dynamics of the top predatory species, and the ability to project changes in tuna distributions and dynamics in response to environmental and climate change.

Extensive research shows how environmental variability affects tuna species in terms population dynamics, distribution and biology and catchability. Additionally, there is increasing evidence that climate change is impacting the physiology, distribution, abundance and reproductive and feeding migrations of tunas (Dufour *et al.* 2010; Bell *et al.* 2013; Dueri, Bopp & Maury 2014; Marsac 2017; Erauskin-Extramiana *et al.* 2019).

However, such research is poorly developed in the IOTC community (Marsac & Marbec 2018).

Tropical tuna species have broad distributions in the tropical equatorial regions of the world oceans and purse seine fisheries that target them usually cover a wide fishing area. This is likely to comprise regions with different environmental characteristics. Accordingly, consideration of the effects of environmental variability should be on a regional basis and at the right temporal and spatial scale (e.g.,

from recruitment variation attributed to local environmental variability, to basic scale redistributions driven by climate change).

It is also important to investigate the combined impact of environmental change and fishing on the dynamic of species to understand if variations result from physical forcing of the environment or fishing. This approach may have important implications for the governance of highly migratory fish stocks as complex environmental-driven variability is an issue for managers.

Ideally ecosystem models are available to evaluate quantitatively how environmental changes propagate through the trophic pathways and affect tuna populations and related fisheries. EwE has increasingly been used in the EPO and WPO to provide ecosystem-based advise for fisheries management (Griffiths & Fuller 2019; Griffiths *et al.* 2019). This is not the case for the IO.

In the last 15 years, other ecosystem models (SEAPODYM (spatial ecosystem and population dynamics model) and APECOSM (Apex Predator Ecosystem model)), have been developed and used to investigate expected variations in a tuna fish population related to changes in the environment, climate and fishing (Dueri & Maury 2012; Lehodey *et al.* 2014). In contrast to the EwE, these two models the population dynamics of a single fish species to investigate the response to different environmental and fishing scenarios.

SEAPODYM was initially developed in the PO and has mostly been used in the WPO to investigate expected changes in tuna fish population in response to ENSO variability. This model allows: (i) investigation of the physical and biological interactions between a top predatory species and the ocean pelagic ecosystem; and (ii) predictions of temporal and spatial distributions of age-structure predator (tuna species) using as drivers a lower-mid-trophic level sub model (describing the dynamics of functional groups of zooplankton and micronekton), and environmental forcing (from temperature, ocean currents) (Lehodey, Senina & Murtugudde 2008).

The SEAPODYM model was developed in the expectation of it being used for management of tuna stocks in the WPO in the context of climate and environmental variability and to investigate the potential impacts of tuna fisheries. It has been tested for skipjack, bigeye and yellowfin stocks (Lehodey 2005; Senina *et al.* 2015, 2016), mainly it appears to understand changes in top predatory tunas under climate change and different fishing strategies, but not to estimate the impact of fishery removals of top predators (from all fisheries) on the structure and function of the ecosystem. Some recent applications of the model have covered temperate tunas in the AO (Dragon *et al.* 2015; Senina *et al.* 2020). The SEAPODYM model has not been applied to tuna species in the IO.

APESCOM is a deterministic model that represents the 3D distribution and population dynamics of tropical tuna under the joint effect of environment conditions and exploitation by fisheries (Dueri, Faugeras & Maury 2012). It has only been applied to the skipjack stock in the IO. It showed that reported catches may be connected to environmental conditions through recruitment dynamics.

Thus, there has been limited application of ecosystem models in the IO to investigate the joint effect of environment and fishing on tuna species and project changes in tuna distributions in response to climate change. Accordingly until quantitative integrated ecosystem models become available, a qualitative expert system approach can only use to infer the potential impacts of environment and climate on tuna, based on the current knowledge and research (Marsac 2017).

5.2.3 *The ecological impacts of selective fishing on the genetic, biology and ecology of species.*

Selective fishing (e.g., specific sizes, specific species, specific behaviours) could change (i) the biology and ecology of the species (modify their behaviour, movement patterns and condition), and (ii) the genetic diversity of species resulting for example in genetically determined change in demographic parameters (e.g., growth, reproductive output).

dFAD fishing has a selectivity pattern for specific sizes of species, specific types of species and specific behaviours. Their use raises the possibility of selective fishing by: (i) Some species are attracted to dFADs more than others. (ii) Tunas, especially in the smaller size range, as well as other pelagic species, tend to aggregate under dFADs, indeed it seems that juveniles of yellowfin and bigeye tuna preferentially aggregate around dFADs. (iii) Species with specific behaviours might preferentially aggregate around dFADs (Hall & Roman 2013); their removal may lead to competitive disadvantages for some species with genetic and ecological implications.

Drifting dFADs might retain tuna species and other species and lead them to locations where they would not normally be found. This may affect their diet, condition, growth and reproductive success.

Both aFADs and dFADs may alter the natural environment or habitat of species. Most experimental studies have focused on investigating the behaviour of tuna using active tracking or passive acoustic telemetry both for aFADs and dFADs (Lopez *et al.* 2017).

The behaviour of pelagic species (mostly tuna species) around aFADs has been easier to study due to their proximity to the coast and fixed location. Studies on tunas behaviour around dFADs are more scarce (with some exceptions in the PO) (Lopez *et al.* 2017).

Taken together, tagging evidence suggest that the behaviour of fish (24 hours dynamics) associated with FADs (aFADs or dFADs) is variable both regionally and by species (Lopez *et al.* 2017). Yet there is evidence that dFADs have the potential to influence the behaviour and movement patterns of tunas and alter the distribution and migration of tunas (Schaefer, Fuller & Block 2011; Leroy *et al.* 2013; Schaefer, Fuller & Aldana 2014; Phillips *et al.* 2017).

A recent experimental study examined the influence of dFADs on tuna movements (Pérez *et al.* 2020). It investigated tuna movements and their dFAD associated behaviour in three different arrays at fine scales, with a different distance from neighbouring dFADs and different dFAD densities. The study suggested that dFAD densities, and in particular their increasing density, may change the behaviour of tunas. It was found that arrays with higher density of dFADs increased the residency time of tunas. A higher density of dFADs reduced the size of tuna aggregation under each, leading to a longer stay at dFADs to allow schools to be large enough to leave (according to the “meeting point” hypothesis).

This experimental study also suggested that an increase in the number of FADs would extend the period of time under the dFADs, thus increasing the vulnerability of tunas to fisheries. Additionally, the authors suggest this may also apply to other species associating with dFADs such as dolphin fish (*Coryphaena hippurus*) and silky sharks (*Carcharinus falciformis*). The authors recommend further studies should be conducted to strengthen their conclusions, with focus on the effect of different FAD densities on species behaviour to support sound management advice.

Another recent experimental study examined the surface-association behaviour of bigeye tuna and yellowfin tunas (tagged with electronic tags) in the presence of dFADs in the WPO (Phillips *et al.* 2017). This found that (i) the surface-associated events of the two species vary greatly; (ii) the big majority of the events were short and (iii) few events were clear and prolonged even in regions with high dFAD deployment. The authors concluded that if the large majority of the residency times of tunas around dFADs are moderately short, there was little evidence to suggest that their biology, movement and behaviour are being significantly affected (Schaefer & Fuller 2010; Phillips *et al.* 2017).

Experimental tagging studies and research to examine the effects of dFADs on the dynamics and behaviour on non-tuna species such as sharks are scarce. The few that are available have shown that tunas and silky sharks closely associated with a dFAD during the day and display similar associative patterns (Forget *et al.* 2015). Available research also suggests that non-tuna species associate strongly to dFADs, leaving them only for short periods (< 2 hours) (Filmalter *et al.* 2011; Forget *et al.* 2015). The similar associative patterns of tunas and silky sharks to dFADs, makes it difficult to find an easy solution to reduce bycatch ratios based on diel associate behaviours around dFADs.

More investigation is needed into the fine-scale behaviour of tunas, silky sharks and oceanic-whitetip shark gain a better understanding of dFAD colonization rates. Both associative daily patterns and swimming depth behaviours may vary between areas (Forget *et al.* 2015).

Based on experimental tagging studies, it is concluded that while there has been considerable work to examine the effects of dFADs on tuna species behaviour and to lesser extent on non tuna species, there remains conflicting interpretations and results on the behavioural impacts of dFADs on pelagic species (Lopez *et al.* 2017). Furthermore, whether the observed changes are temporal and are reversible or whether they are producing serious or irreversible harm to the species biology remains largely unknown.

Some experimental studies have investigated the feeding habits of tuna species and their growth associated with aFADs, dFADs and free swimming schools (Ménard *et al.* 2000; Jaquemet, Potier & Ménard 2011). Available results suggest that differences in size observed between tunas in free swimming schools and dFADs might be variable, but studies show opposite patterns, making inferences of the ecological impacts of dFADs on size difficult (ISSF 2014). These studies have found that around aFADs tuna prey on a diverse assemblage of species, whereas around dFADs, they prey on a lower diversity of preys and empty tuna stomachs are found more often.

These findings seem reasonable as food is more patchily distributed in oceanic waters and tunas have adapted to this by inhabiting more productive waters (sets on free schools occur in more productive waters) and swimming deep below the thermocline to prey on mesopelagic species.

Moreover, there is increasing evidence that FADs, especially dFADs, do not have a feeding function for tunas, as they feed on species that do not associate with dFADs and feed during excursions away from the dFADs (Ménard *et al.* 2000; Jaquemet, Potier & Ménard 2011). However, the location of a FAD and the availability of prey near them, especially aFADs, may be a factor explaining the associated behaviour of species in FADs (Ménard *et al.* 2000; Jaquemet, Potier & Ménard 2011).

Taken together, the evaluation of the impacts of dFADs on the condition of tunas and their behaviour is complex and an active area of research, since their impact seems to be location, species and size dependent (Jaquemet, Potier & Ménard 2011; ISSF 2014).

An alternative to experimental tagging studies is to use data provided by fishers' echo-sounder buoys to study the collective dynamics of fish aggregations. Purse seiners place satellite linked buoys equipped with eco-sounder on the dFADs to estimate the fish biomass underneath. These allow study at a large scale on the simultaneous associative behaviour of all fish (target and non-target) linked to dFADs.

Such research has recently started. The first study investigated the fine-scale (24 hours dynamics) of multi-species aggregations at dFADs in different areas of the WIO (Lopez *et al.* 2017). It found periodicity and region and species-specific associative behaviour with dFADs, suggesting that potential ecological interactions exist. However, the reasons behind regional and species-specific differences remain unclear, and a better understanding of these interactions would require comparison of associated behaviour of species at dFADs (e.g. residency time) with fine-scale environmental drivers, information on the local community structure around the dFADs and prey availability (using video recorders around dFADs).

Another way to investigate the potential impacts of dFADs on ecosystems is by studying their spatial and temporal dynamics in comparison to natural logs. In the WIO, Dagorn *et al* 2013 compared the spatial distribution of natural (logs) and artificial floating objects (dFADs) using the data from observer programs in the tuna purse seine fishery. The authors calculated the proportion of dFADs observed in spatial grids without natural logs (using spatial grids sizes of 1^ox1^o, 2° x 2°, 5° x 5° and 10^ox10^o). The study suggested that (i) dFADs do not create additional habitats at larger spatial scales (grids > 2^ox 2°) (ii) dFADs could drive tuna to new areas (with potential consequences for the movement and biology of the species) at scales smaller than the 2° x2^o grid, and since tuna are known to travel long distances

(exceeding the 2 º x2 º grid), it is reasonable to consider that the ecological consequences of tunas being displaced to areas where they would not have been are small (Dagorn *et al.* 2013b). However, while it was shown how dFADs have drastically increased the number of objects in the spatial grids examined, the study did not consider the effects of different densities of dFADs on tuna movement.

Identifying drivers of pelagic species behaviours around aFADs or dFADs remains a challenge. Understanding of the effects of increasing the number of dFADs and their density on the behaviour and biology of the species being aggregated around them remains an active area of research. However, there is emerging evidence that FAD densities influence the behaviour of the species (Perez *et al* 2020).

To test whether dFADs may affect the behaviour and large-scale movements of tunas, the latter would need to be compared before and after large-scale deployment of dFADs. This is impractical as the currently available data and related research are not available (ISSF 2014).

Alternatively, future studies could use instrumentation around dFADs (echo-sounder buoys and others) to record information on (i) the biomass of species aggregations, (ii) the drifting FAD movement, and (iii) local environmental conditions, with a combination of passive receivers for acoustic tags deployed on tunas and other pelagic species.

This combination of technology around dFADs has the potential to create an ocean network of autonomous observation stations to assist fishery managers and decision makers in the conservation and management of pelagic species (Moreno *et al.* 2016).

5.2.4 *The ecological impacts of marine debris via the introduction of toxic substances and microplastic on the ecosystem*

As the impacts of ALDFG via the introduction of toxics substances and microplastics into the food chains has not been considered in C2.5 assessments of purse seine tuna fisheries, this aspect is not covered in this report.

5.3 Summary of information and research

Table 6 identifies the ecosystem impacts relevant to purse seine tuna fisheries by those (i) with adequate information and detailed study, and (ii) that have not been investigated in detail and are poorly understood.

6. ASSESSMENT OF THE ADEQUACY OF AVAILABLE INFORMATION ON THE IMPACT OF AN UOA ON INDIVIDUAL KEY ECOSYSTEM ELEMENTS

6.1 Approach

This analysis focuses on the pelagic ecosystem of the tropical IO to examine existing research that (i) assesses the potential ecological impacts of the Echebastar Fishery on individual key ecosystem elements and (ii) allow some of the main consequences to be inferred. Three[9] potential ecosystem impacts are considered.

- The ecological impacts of fishery removals of top predators on the structure and function of the marine ecosystem.
- The effect of natural environmental variability (including climate change) on ecosystem productivity and tuna dynamics.
- The ecological impacts of FAD use on the genetic, biology and ecology of species (tunas and non-tunas).

[9] This report does not review the ecological impact of introducing marine debris (via microplastics) from abandoned, lost or discarded fishing gears on the food web.

Table 6. Summary of available information & research on ecosystem impacts.

Type of ecosystem impacts relevant to tropical purse seine fisheries	Ecosystem impacts with relevant information and research	
	IO	**Other equatorial oceans**
Ecological impacts of fishery removals of top predators via the alteration of trophic relationships on the structure & function of the marine ecosystem	Not investigated in detail and poorly understood	**EPO & WPO**: Relatively well investigated and understood. **Atlantic**: Not investigated in detail and poorly understood
Ecological impacts of fishery removals of species (top predators / other species in the foodweb) via the truncation of size composition on the structure & function of marine ecosystem.		**North Pacific Ocean**: Some size-based ecosystem models have been developed and investigated in some detail. **EPO, WPO & Atlantic Ocean:** Not investigated in detail and poorly understood.
Ecological impacts of fishery removals of species (top predators/r other species in the foodweb) via the alteration of diversity on the structure and function of marine ecosystem.		**EPO & WPO**: Some aspects investigated. **Atlantic**: Not investigated in detail and poorly understood
Effect of large scale climatic and oceanographic physical forcing (natural environmental variability) on ecosystem productivity and tuna dynamics	Relatively well investigated with some aspects understood.	**WPO & EPO**: Relatively well investigated and understood.
Effects of climate change on ecosystem productivity & tuna dynamics		

Ecological impact of FAD use via selective fishing on the genetic, biology & ecology of tunas	• Some elements are well investigated and relatively well understood. • There has been considerable research (experimental tagging studies, and studies using fisher's echosounder buoy data) examining the effects of dFADs (mostly presence of dFADs) on the behaviour, movement patterns of tunas and their consequences on the biology of the species (e.g. growth). • More studies are required to understand better the effects of increasing number of dFADs and FAD densities on the behaviour, movement patterns of tunas.
Ecological impact of FAD use via selective fishing on the genetic, biology & ecology of non-tunas	• Research (experimental tagging studies, and studies using fisher's echosounder buoy data) examining the effects of dFADs (mostly presence of dFADs) on the behaviour, movement patterns of non-tuna species, especially ETP species such as sharks, and their consequences on the biology of the species (e.g. growth)are relatively scarce. • More studies are required to understand better the effects of increasing number of dFADs and FAD densities on the behaviour, movement patterns of non-tuna species.
Ecological impact of fishing via the introduction of microplastic pollution into the food web	Not assessed.

6.2 Ecological impacts of fishery removals of top predators on the structure and function of marine ecosystem

Research completed in a number of countries has collected and analysed data to improve understanding of the ecological impacts of fishing on the structure and function of the IO pelagic ecosystem. Focus has been concentrated on (i) the collection of bycatch composition and quantities in the fishery observer programs, (ii) trophic analyses (e.g. stomach contents, stable isotopes) and behavioural studies of species with tagging programs, and (iii) developing ecological indicators on the impacts of fishing on the ecosystems using trophic based and size based indicators of the catches derived from the purse seine observer programs (Andonegi *et al.* 2019; Juan-Jordá *et al.* 2019b; a). However, these type of research and studies have not been continuous in space and time. At the level of IOTC region, bycatch, trophic and *ad hoc* tagging studies have been mostly conducted on a project-by-project basis by individual countries, with little integration of knowledge at the regional level of IOTC.

Extensive studies have not been undertaken on the ecological communities of tuna species to understand their roles as a key predator and prey species within the foodweb of the IO. Compared to the Atlantic and Pacific oceans, there have been relatively few research studies studying the trophic ecology for IOTC tuna species, species interactions and their ecological role in the food web (Olson *et al.* 2016). There remains relatively limited understanding of the linkages between functional groups and how these may be affected by IO fisheries.

Furthermore, ecosystem modelling to inform IO management of top predatory species is in its infancy (Juan-Jordá *et al.* 2019b).

The lack of solid research and ecosystem modelling (trophic-based or size-based ecosystem models) for the IO limits investigation of the impact of biomass removals of all fisheries combined (or the relative removals by different fisheries) on ecosystem structure and function, and to assess if these effects are causing serious or irreversible harm. Accordingly, informed understanding of the pelagic food web dynamics and the impact of fishing must be derived from the Pacific Ocean where most of the ecosystem modelling in the context of tuna fisheries has been carried out.

However, note two relevant points at the scale of the IOTC region: (i) the continued productivity of the purse seine fishery in the IO could be interpreted as evidence that the structure and function of the ecosystem has not been compromised by the fisheries; and (ii) the purse seine fisheries target skipjack, yellowfin and bigeye tunas and these species are above their respective points of recruitment impairment (PRI). In the absence of other information, PRI could be used as a suitable trigger to infer the risk of irreversible ecosystem impacts.

It is important to bear in mind that the Standard relates to the impact of an UoA on key elements underlying ecosystem structure and function, and not to the cumulative impacts of all tuna fisheries operating in the IO.

The main impacts of Echebastar removals of top predators could be partially inferred using (i) data directly from the fishery (logbook and observer program), (ii) existing knowledge and understanding of ecosystem dynamics using ecosystem models carried out in other oceans, (iii) IOTC fishery stock assessment of tropical tuna, and (iv) preliminary research on ecological indicators monitoring impacts of purse serine biomass removals.

In the UoC, 100% observer coverage has improved understanding of bycatch composition and quantities, is increasing the amount of relevant ecological data and has allowed bycatch studies to be conducted at relevant temporal and spatial scales.

Based on the current research and ecosystem modelling done mainly in the PO, it also seems reasonable to conclude that (i) adequate information is available to allow some of the main

consequences for the ecosystem to be inferred, but (ii) adequate information is not available to allow for the main ecosystems impacts to be inferred with certainty.

While the western IO lacks a reliable ecosystem model that examines the potential ecological impacts of fishery removals of top predators (or the effects of the environment) on the ecosystem function and structure of the ecosystem. The modelling work in other oceans, mainly the PO, allows understanding of the pelagic food web dynamics and the impact of predatory removals on the foodweb dynamics in the IO. The state of research in the WPO and EPO allows the conclusion that after 50-60 years of industrial fishing, the removal of top predators has not been detrimental to the structure and function of the eastern and western equatorial ecosystem to the point where there would be a serious or irreversible hard

Moreover, Echebastar harvests a limited proportion of the total catch of the three tuna species in the IO. As such, it is highly unlikely that this fishery by itself could lead to irreversible harm to key ecosystem elements. But there is no hard evidence that this is the case.

However, the lack of specific ecosystem indicators and ecosystem models in the Echebastar fishing area makes it difficult to simulate and infer the main consequences of the impacts of the UoC on the ecosystem with certainty. There is no hard evidence that the UoC is highly unlikely to disrupt the key elements underlying ecosystem structure and function by the removal of predatory fishes and the likely changes to mid-trophic level species abundances to a point where there would be serious or irreversible harm. Nor is there evidence that changes in the trophic structure and function resulting from all fishing activities (purse seine and longline fisheries) have not been detrimental in the IO and that a recovery of ecosystem structure to its pre-industrial period is plausible.

In the IO, research efforts have traditionally been focused on understanding the effect of fishing on the stock size, reproductive capacity and size distribution of skipjack, yellowfin and bigeye. More research is needed to understand the implications of biomass removals on the pelagic foodweb.

6.3 The effect of natural environmental variability and human induced climate change on the ecosystem productivity and tuna dynamics

The Standard requires that "*UoAs should be capable of adapting management to environmental changes as well as managing the effect of the UoA on the ecosystem*" and "*Monitoring the effects of environmental change on the natural productivity of the UoAs should be considered best practice and should include recognition of the increasing importance of climate change*".

It is known that natural large-scale changes in biological production in the IO have resulted from linked climatic and oceanographic physical forcing (Ternon *et al.* 2014; Marsac 2017; Erauskin-Extramiana *et al.* 2019). Extensive environmental data (physical and biological data) is available (e.g., World ocean atlas, remote sensing data, ocean circulation models, climate models) and continues to be collected. Considerable research has (i) focused on understanding the changes in ocean circulation, temperature, salinity, stratification and production in the IO (Marsac 2017), and (ii) been done to understand how the natural environmental variability and climate change affect the dynamics of top predators such as tunas (Ternon *et al.* 2014; Marsac 2017; Erauskin-Extramiana *et al.* 2019). Most of the research of the effects of the environmental on predatory fish species has focused on tuna species and, to a lesser extent, non-tuna species such as sharks (Marsac 2017; Erauskin-Extramiana *et al.* 2019).

Despite the completed research, more is needed with the support of ecosystem modelling to evaluate different environmental and climate scenarios, in combination with different fishing scenarios, and their effect on the dynamics of top predatory species. This would allow the main consequences of environmental changes and fishing on the ecosystem to be inferred. The current situation is that the lack of ecosystem models of any type (EwE, SEAPODYM, APECOSM) in the IO does not allow

investigation of the joint effect of environment and fishing on tuna species, and project changes in tuna distributions in response to climate change. In the absence of quantitate integrated ecosystem models, only qualitative expert system approach is available to infer what might be the potential impacts of environment and climate on tuna based on the current knowledge and research (Marsac 2017).

No doubt, there is increasing recognition of the importance of natural environmental variability and climate change and its effect on fisheries resources. This is reflected by the increased research (e..g. Marsac 2017; Erauskin-Extramiana *et al.* 2019). More work is needed to see how fisheries may adapt to management to environmental changes and climate change, while managing the effect of fishing on the ecosystem.

Adapting fisheries management to environmental changes and climate change effects needs to be supported by extensive research to understand the links between environmental variability and climate change on the productivity of the ecosystem, including the potential effects on species distribution and populations dynamics of tunas (e.g., recruitment, growth). These links need to be well understood and monitored to support management strategies.

6.4 The ecological impacts of selective fishing on the genetic, biology and ecology of species

Many experimental tagging studies have examined the effects of dFADs on tuna species behaviour and movement patterns. More recent studies using fishers' echo-sounder buoys data have studied collective dynamics of fish aggregations around dFADs (Hall & Roman 2013; Lopez *et al.* 2017; Pérez *et al.* 2020). To a lesser extent, experimental studies have investigated the feeding habits of tuna species and their conditions (growth) associated with aFADs and dFADs and free swimming schools (Ménard *et al.* 2000; Jaquemet, Potier & Ménard 2011).

Most experimental studies investigating the effects of dFADs on pelagic species behaviour and movement patterns have taken place in the PO and IO with focus on the behaviour and movement patterns of major tuna species and to lesser extent on other species such as sharks. These studies provide some evidence that the increasing use of dFAD sets in purse seine fisheries might be changing how tuna species and other pelagic species use their habitats; distributions, migrations and biology (Leroy *et al.* 2013; Schaefer, Fuller & Aldana 2014; Phillips *et al.* 2017).

However, taken together, experimental tagging studies suggest that the behaviour of fish (24 hours dynamics) associated to FADs (aFADs and dFADs) is regionally and species variable (Lopez *et al.* 2017). There is limited understanding on (i) the influence of dFADs on the residency of tunas and other non-tuna species, and (ii) how the increased number of dFADs is affecting the school sizes of tunas and other species. Accordingly, there remain conflicting interpretations and results on the behavioural impacts of dFADs (and the different densities of dFADs) on tunas and the potential consequences on their biology (Dagorn *et al.* 2013b; Lopez *et al.* 2017). This makes it difficult to infer all the main consequences of the impact of FAD use on tuna species, and even more so on non-tuna species such as sharks for which the research is more limited.

Another way to investigate the potential impacts of dFADs on ecosystems is by studying their spatial and temporal dynamics in comparison to natural logs. A study conducted in the western IO suggests that the ecological consequences of tunas being displaced by dFADs to areas where they would not have been, are small (Dagorn *et al.* 2013b) (see above).

It is important to bear in mind that the Standard relates to the impact of an UoA on key elements underlying ecosystem structure and function, and not to the cumulative impacts of all tuna fisheries (or all dFADs from all the fisheries) operating in the IO. To evaluate the impact at the scale of the UoC, would need knowledge of the number of dFADs deployed per vessel and year relative to the total number of dFADs deployed in total by the whole fishery, how it varies by region and their drifting

trajectories. A tracking program could support management of the number of dFADs deployed in and drifting in the region.

The Echebastar fishery only accounts for a small proportion of the dFADs deployed in the area, and it is highly unlikely to disrupt the behaviour, movements patterns and condition of pelagic species to a point where there would be a serious irreversible hard. But there is no hard evidence that this is the case.

Data collection (fish logbooks, FAD logbooks, comprehensive observer programmes, dFAD-tracking programme) may be sufficient to detect any increase in risk level at the scale of UoC, at least by monitoring the number and extent of FAD use. While observer programs have been designed mainly to monitor the impacts of the fishery on target and non-target species, they may also provide adequate data to monitor FAD impacts and to detect any increased risk.

Similarly, data collected by the UoC level might be sufficient to support the development of strategies to manage ecosystems impacts, even if a full ecosystem strategy is not feasible for the fishery or at the IOTC level.

7. SHADOW SCORING FOR PI 2.5.1 & PI 2.5.3 FOR THE ECHEBASTAR PURSE SEINE FISHERY

7.1 Approach

To provide a shadow scoring for PI 2.5.1 and PI 2.5.3, three ecosystem impacts were considered as the main subjects of evaluation (tables 7 and Table 8): (1) the ecological impacts of fishery removals of top predators on the structure and function of marine ecosystem; (2) the effect of natural environmental variability (including climate change) on ecosystem productivity and tuna dynamics; and (3) the ecological impact of FAD use on the genetic, biology and ecology of species (tunas and non-tunas) on the genetic, biology and ecology of species.

Table 7: Scoring Table PI 2.5.1 – Ecosystem outcome

PI 2.5.1		**The UoA does not cause serious or irreversible harm to the key elements of ecosystem structure and function**		
Scoring Issue		SG 60	SG 80	SG 100
a	Ecosystem status			
	Guide post	The UoA is **unlikely** to disrupt the key elements underlying ecosystem structure and function to a point where there would be a serious or irreversible harm.	The UoA is **highly unlikely** to disrupt the key elements underlying ecosystem structure and function to a point where there would be a serious or irreversible harm.	There is **evidence** that the UoA is highly unlikely to disrupt the key elements underlying ecosystem structure and function to a point where there would be a serious or irreversible harm.
	Met?	**Y**	**Y**	**N**
The ecological impacts of fishery removals. The total removals of tropical tunas in the IO were in excess of 1 million mt in 2019, of which the Echebastar fishery accounts for a small proportion. As such it is unlikely that this fishery by itself disrupt the key elements underlying ecosystem structure and function to a point where there would be a serious or irreversible harm.				

SG60 is met.

Biomass at PRI could be used as a suitable trigger, in the absence of other information, to infer whether irreversible ecosystem impacts might be expected. The continued productivity of the purse seine fishery in the IO could be interpreted as evidence that the structure and function of the ecosystem has not been compromised by the fishery. This fishery targets skipjack, yellowfin and bigeye, none which are currently below or even near their respective PRI.

This, in addition to the scale of the Echebastar fishery as a proportion of the total fishery allows the conclusion that it is highly unlikely to disrupt key ecosystem elements of the ecosystem (trophic structure, size structure and diversity) to a point where there would be a serious or irreversible harm.

SG80 is met.

Research has focused on understanding the effect of fishing on skipjack, yellowfin and bigeye tuna stock size, reproductive capacity and size distribution, but not on understanding the implications of these biomass removals on the pelagic foodweb. This, and the lack of ecosystem modelling, means that there has not been an assessment of the impact of biomass removals from all fisheries on the ecosystem and whether this has been disrupted to the point of irreversible harm. Even though the Echebastar fishery comprises a small part of the total fishery, this lack of evidence applies to the UoC and prevents a conclusion sufficient to meet the SG.

SG100 not met.

The effect of natural environmental variability.

This PI refer to the impact of UoA on key elements underlying ecosystem structure and function. It does not consider the effect of natural environmental variability and human induced climate change on ecosystem productivity, even though it is known there are natural large-scale changes in biological production in the IO resulting from linked climatic and oceanographic physical forcing. Multiple research studies have documented how different ecosystem component, principally the tunas and to lesser extent non-target species such as sharks, respond to such environmental changes and climate change (Marsac 2017; Erauskin-Extramiana *et al.* 2019)

Scoring not applicable.

The ecological impact of FAD use.

There are some concerns that dFAD sets might change how tuna and other pelagic species use their habitats with changes in distribution, migration and biology. Evidence exists that dFADs have the potential to influence the behaviour and movement patterns of tunas and alter their distribution and migration (Leroy *et al.* 2013; Schaefer, Fuller & Aldana 2014; Phillips *et al.* 2017) .Taken together experimental tagging studies suggest that the behaviour of fish (24 hours dynamics) associated to dFADs (aFADs or dFADs) is variable, regionally variable and species variable (Lopez *et al.* 2017).

Scoring is specific to an UoA and not to the cumulative impacts of all tuna fisheries (and all dFADs) operating in the IO. In perspective, the Echebastar fishery only accounts for a small proportion of the dFADs deployed in the IO (arounds 12%), it may be inferred that it is highly unlikely to disrupt the behaviour, movements and biology of pelagic species to a point where there would be a serious irreversible hard.

SG60 & SG80 are met.

A study in the western IO (Dagorn *et al* 2013) compared the spatial distribution of natural floating objects (logs) and artificial floating objects (dFADs) using data from the observer programs in the tuna purse seine fishery, by calculating the proportion of dFADs observed in spatial grids (sizes of 1^ox1^o, 2° x 2°, 5° x 5° and 10° x10^o) without natural logs.

The study concluded that:

- dFADs do not create additional habitats at larger spatial scales (grids > 2^ox 2°)

• dFADs would not drive tuna to new areas (with potential consequences to movements and biology of the species) at scales smaller than the 2 º x2 º grid as they are known to travel greater distances (exceeding the 2 º x2 º grid). As such, it is reasonable to consider that the ecological consequences of tunas being displaced to areas where they would not have been are small (Dagorn *et al.* 2013b). However, while this study shows that the growth in numbers of dFADs has drastically increased the number of objects in the spatial grids examined, the effects of different densities of dFADs on tuna movement were not addressed. In addition, Perez *et al.* 2020 indicated, for the first time, that increasing aFAD densities may change the behaviour of tunas. As Perez *et al* point out, research into the effects of increasing number of dFADs and FAD densities on the behaviour and biology of the species being aggregated around dFADs is active, and further studies are needed to corroborate their findings. There is not the evidence to satisfy SI 100 or conclude that the SG is partially met. **SG100 is not met.**	
Estimated score	**Both elements meet 80 but not 100.** **Score = 80.**

Table 8 Scoring Table PI 2.5.3 – Ecosystem information

PI 2.5.3		**There is adequate knowledge of the impacts of the UoA on the ecosystem**		
Scoring Issue		SG 60	SG 80	SG 100
	Information quality			
a	Guide post	Information is adequate to **identify** the key elements of the ecosystem.	Information is adequate to **broadly understand** the key elements of the ecosystem.	
	Met?	**Y**	**Y**	

Over recent years, data has been collected and studies completed to improve understanding of the ecological impacts of fishing on the structure and function of the IO pelagic ecosystem. Examples are: data on bycatch composition and quantities through the fishery observer programme, trophic analyses (e.g. stomach contents, stable isotopes), behavioural studies with tagging programs, and the definition of ecological indicators (e.g. trophic based and size based indicators) to monitor the potential impact of tuna removals from the ocean (Andonegi *et al.* 2019; Juan-Jordá *et al.* 2019b).

In line with the analysis contained in PI 2.5.1 this information indicates that it is possible to identify and describe what are the main ecological impacts of the fishery and what ecosystem elements and attributes need to be monitored to assess the impacts:

- The ecological impacts of fishery removals of top predators on the structure and function of marine ecosystem (ecosystem elements: i.e. the impact of removals on the biomass of ecological community, size structure of the ecological community, trophodynamics of ecological community)
- The effect of natural environmental variability (including climate change) on ecosystem productivity and tuna dynamics (ecosystem elements: i.e. effect of environmental and climate scenarios of temperature, salinity, chlorophyl-a, oxygen, on tuna dynamics)
- The ecological impact of FAD uses on the genetic, biology and ecology of species (tunas and non-tunas) on the genetic, biology and ecology of species (ecosystem elements: i.e. the impact of FAD use on the genetic, biology and ecology of species)

SG60 is met.

100% observer coverage for the Echebastar fleet has improved the understanding of bycatch composition and quantities, is increasing the availability of relevant data and is allowing bycatch studies to be conducted at relevant temporal and spatial scales.

At the scale of the IO, trophic and ecological indicator analysis continue to be conducted on a project-by-project basis by individual. This has resulted in studies that are not continuous in space and time, which limits the integration of knowledge at the regional level of IOTC.

Furthermore, extensive trophic studies have not been undertaken on tropical tuna species to understand their role as a key predator and prey species within foodweb in the IO. Compared to the Atlantic and Pacific Ocean, there have been relatively few research studies studying the trophic ecology for IO tuna species, species interactions and their ecological role in the food web (Olson *et al.* 2016). The development and use of ecosystem models in the Indian Oceans to inform fisheries management of top predatory species is in its infancy (Juan-Jordá *et al.* 2019b). This means there is relatively limited understanding of the linkages between functional groups and how these may be affected by IO fisheries.

Considerable research has focused on understanding (i) the changes in ocean circulation, temperature, salinity, stratification and production in the IO (Marsac 2017) and (ii) how natural environmental variability and climate change affect the dynamics of top predators such as tunas (Marsac 2017; Erauskin-Extramiana *et al.* 2019).

In addition, (i) experimental tagging studies have examined the effects of dFADs on tuna species behaviour and (ii) studies using the fisher's echo-sounder buoys data to study collective dynamics of fish aggregations (instead of using the data from tagging individuals) around dFADs (Hall & Roman 2013; Lopez *et al.* 2017; Pérez *et al.* 2020)

In sum, the information is adequate to identify the key types of ecosystem impacts relevant to an assessment of tuna purse seine fisheries under P2.5.

SG80 is met.

	Investigation of UoA impacts			
b	Guide post	Main impacts of the UoA on these key ecosystem elements can be inferred from existing information, but **have not been investigated** in detail.	Main impacts of the UoA on these key ecosystem elements can be inferred from existing information, and **some have been investigated in detail**.	Main interactions between the UoA and these ecosystem elements can be inferred from existing information, and **have been investigated in detail**.
	Met?	**Y**	**Y**	**N**

The ecological impacts of fishery removals:

Trophic-based or size-based ecosystems of the pelagic food web in the IO is in its infancy. Thus the western IO lacks a reliable ecosystem model that examines the potential ecological impacts of fishery removals of top predators (or the effects of the environment) on the ecosystem function and structure of the ecosystem. However, modelling work in other oceans, mainly the PO, allows understanding of the pelagic food web dynamics and the impact of predatory removals on the foodweb dynamics in the IO.

The main impacts of Echebastar fishery removals of top predators may be inferred from:

- Vessel logbooks and observer data,
- IOTC tuna stock assessments,

- Some preliminary ecological indicators from the monitoring of impacts of purse serine biomass removals, and
- Understanding of ecosystem dynamics using several ecosystem models carried out in other oceans,

that together contribute an understanding of the potential ecological effects of purse seine fishery removals of predatory fishes on the structure and function**.**

SG60 is met.

The modelling work in the PO provides evidence that some of the main impacts have been investigated in detail.

SG80 is met.

The main ecological impacts of fishery removals by the UoA on the structure and function of the marine ecosystem have not been investigated in detail.

SG100 is not met.

The effect of natural environmental variability:

The Standard states that "*UoAs should be capable of adapting management to environmental changes as well as managing the effect of the UoA on the ecosystem*" and "*Monitoring the effects of environmental change on the natural productivity of the UoAs should be considered best practice and should include recognition of the increasing importance of climate change*".

Considerable research allows understanding of the importance of physical and biological drivers in tuna distributions, tuna dynamics (recruitment processes) and tuna catchability in the IO (Marsac 2017).

SG60 is met.

There is a lack of ecosystem models (EwE, SEAPODYM, APECOSM) in the IO to (i) investigate the joint effect of environment and fishing on tuna species, and (ii) project changes in tuna distributions in response to climate change. In the absence of quantitate integrated ecosystem models, based on current knowledge and research, a qualitative expert system approach can infer the potential impacts of environment and climate on tuna (Marsac 2017).

SG80 is met.

Incorporating environmental and climate change into the fisheries management decision making process requires the support of research to understand the links between environmental variability and climate change on the productivity of the ecosystem, including the potential impact on tuna distribution and populations dynamics, and monitor any changes. To-date this has not been investigated in detail.

SG100 is not met.

The ecological impact of FAD use:

Experimental tagging studies have examined the effects of dFADs on tuna species behaviour. In addition, research using data from fisher echo-sounder buoys has studied the collective dynamics of fish aggregations around dFADs in the IO and elsewhere (Lopez *et al.* 2017; Pérez *et al.* 2020). These allow inference of the impact of dFAD use on species behaviour, migrations and biology.

SG60 & SG80 are met.

There remain conflicting interpretations and results on the behavioural impacts of dFADs on tunas and the potential consequences on their biology (Dagorn *et al.* 2013b; Lopez *et al.* 2017). While the Echebastar fishery only accounts for a small proportion of the dFADs deployed in the IO, there is limited understanding of (i) the influence of dFADs on the residency of tunas and other non-tuna species, and (ii) how the increased

number of dFADs is affecting the school sizes of tunas and other species that may impact their behaviour, migration and biology.

The impacts of FAD use on behaviour, migrations and biology, and the effects of increasing number of dFADs and dFAD density on the behaviour and biology of the species being aggregated are subject of active research and only some have been investigated in detail.

SG 100 is not met.

	Understanding of component functions		
c	Guide post	The main functions of the components (i.e., P1 target species, primary, secondary and ETP species and Habitats) in the ecosystem are **known**.	The impacts of the UoA on P1 target species, primary, secondary and ETP species and Habitats are identified and the main functions of these components in the ecosystem are **understood**.
	Met?	**Y**	**N**

As evidenced by C2.1, C2.2, C2.3 and C2.4, sufficient information is available to identify the range of species (main, secondary, ETP species and habitat) that interact with the Echebastar fishery. For many, their main functions in the ecosystem are known; transferring energy between trophic levels, and their trophic role as high level predators.

SSG80 is met.

In comparison to the Atlantic and Pacific Ocean, there has been relatively little research into the IO trophic ecology of tuna species, species interactions and their ecological role in the food web (Olson *et al.* 2016). Accordingly, there is relatively limited understanding of the linkages between functional groups and how these may be affected by IO fisheries. As such, while the impacts of the UoA on the components have been identified, the functions of these are only generally understood.

SG100 is not met.

	Information relevance		
d	Guide post	Adequate information is available on the impacts of the UoA on these components to allow some of the main consequences for the ecosystem to be inferred.	Adequate information is available on the impacts of the UoA on the components **and elements** to allow the main consequences for the ecosystem to be inferred.
	Met?	**Y**	**N**

The ecological impacts of fishery removals:

The ecosystem impacts of fishery removals by Echebastar have not been formally quantified by monitoring the changes in the foodweb structure or size structure of the communities using indicators and ecosystem models. Yet the total removals of the Echebastar fishery are known (biomass, species composition and size composition) from data provided by the logbooks and fishery observer programme.

Simple ecological indicators could be developed using this data to better understand the impacts of the UoC on the structure and function of the marine ecosystem. However, full analysis would require data on the impacts of total fish removals by all fisheries on the structure and function of marine ecosystem by types

of fisheries. The development of ecosystem models would allow to understand better and simulate the main consequences of partial removals by a fishery or total removals from all fisheries on the ecosystem.

The information available (extensive observer coverage records of removals of target and non-target species, trophic ecology studies of the species) might be sufficient to support the development of some ecological indicators (trophic-based, size based, biomass based) in the IO, but as yet this work is poorly developed (Andonegi *et al.* 2019; Juan-Jordá *et al.* 2019b).

Also relevant is that currently none of the main target species are below (or near) their respective PRIs; . biomass at PRI could be used to infer main consequences for the ecosystem.

Adequate information and research is available on the impacts of the UoA via predator removals on the structure and function of the ecosystem to allow only some of the main consequences for the ecosystem to be inferred.

SG80 is met.

The available information on the impacts of the UoA on the components **and elements** is not adequate to allow the main consequences for the ecosystem to be inferred.

SG100 is not met.

The effect of natural environmental variability:

This element does not require evaluation of whether enough environmental data is being collected to measure the effect of natural environmental variability and human induced climate change on the ecosystem productivity of the region.

Scoring not applicable.

The ecological impact of FAD use:

Some information is available from dedicated research projects regarding the impact of FAD use on the migration, behaviour and biology of tuna species in the IO as well as other oceans. Experimental tagging studies have examined the effects of dFADs on tuna species behaviour and there has been research using fishers' echo-sounder buoys data to study collective dynamics of fish aggregations around dFADs in the IO and elsewhere (Lopez *et al.* 2017; Pérez *et al.* 2020). These studies area available to infer some of the main consequences of dFAD use on species behaviour, migrations and biology.

SG80 is met.

There remain however conflicting interpretations and results on the behavioural impacts of dFADs on tunas and their potential consequences on their biology (Dagorn *et al.* 2013b; Lopez *et al.* 2017), which makes it difficult to infer all the main consequences of the impact of FAD use on tuna species. The limited availability of relevant research, makes it is even more difficult to analyse the dFAD impact om non-tuna species such as sharks.

There is limited understanding on (i) the influence of dFADs on the residency of tunas and other non-tuna species, and (ii) how an increase in the number of dFADs could affect the school sizes of tunas and other species, which leads to disruption in the behaviour, migration and biology of pelagic species (Pérez *et al.* 2020).

Further research is needed to understand better the potential impacts of high FAD densities in certain regions of the fishing grounds, which could assist in better understanding the relative impacts of the UoA Echebastar on the species behaviour, migration and biology.

SG100 is not met.

e **Monitoring**

Guide post	Adequate data continue to be collected to detect any increase in risk level.	Information is adequate to support the development of strategies to manage ecosystem impacts.
Met?	**Y**	**N**

The ecological impacts of fishery removals:

While the observer programs have been designed mainly to monitor the impacts of the fishery on target and non-target species rather than monitoring ecosystem impacts, this together with logbooks and data on dFADS is sufficient to detect any increase in risk level.

SG80 is met.

Trophic studies that have taken place are typically not continuous in space and time. Extensive studies have not been undertaken to understand the role of tropical tuna species as key predator and prey species within the IO foodweb. Compared to the Atlantic and Pacific Ocean, there have been relatively few research studies studying the trophic ecology for IOTC tuna species, species interactions and their ecological role in the food web (Olson *et al.* 2016).

While the data collected by the UoC might be sufficient to support the development of strategies to manage its ecosystems impacts, this would need to incorporate broader ecosystem information (e.g., size structure of the species, trophic ecology of the species) than currently available. IOTC does not have a comprehensive strategy for ecosystem management.

SG 100 is not met.

The effect of natural environmental variability:

Extensive environmental data is available and continues to be collected (e.g., World ocean atlas, remote sensing data, ocean circulation models, climate models) that would allow any increase in risk to be detected.

SG80 is met.

This data need to be supported by extensive research to understand the links between environmental variability and climate change on the productivity of the ecosystem, and the effect on tuna distribution and populations dynamics. The links need to be understood and monitored so management strategies may be developed to account for the effect of natural variability and climate change on the tuna species under management.

SG100 not met.

The ecological impact of FAD use:

Data collection by the UoC is sufficient to detect any increase in risk level associated with it, but not at the scale of all purse fisheries operating in the IO. The observer programme provides adequate data to monitor ecosystem impacts (e.g. understanding FAD use on the behaviour, migrations and biology of pelagic species), and is sufficient to detect any increase risk at the scale of UoC.

SG80 is met.

Similarly, the data collected at the UoA level might be sufficient to support the development of strategies to manage ecosystems impacts, even if a full ecosystem strategy is not in place by the fishery. IOTC does not have either a comprehensive strategy for ecosystem management in place and there is no information to put the UoC in the context of the whole fishery.

SG100 is not met.

Estimated score 80

7.2 Scoring Rationales and Estimated Score

On the basis of the rationale provided, in the opinion of the consultant, both PI 2.5.1 and PI 2.5.3 achieve a score of 80 for the Echebastar fishery.

8. CONCLUSIONS & RECOMMENDATIONS

8.1 Introduction

The objectives of the work were defined in the ToR (Appendix 1).

Review and analysis have covered a number a issues that (i) inform SIOTI its potential C2.5. work plan for the remaining two years of its fishery improvement project (FIP) in relation to meeting the MSC standard for each of the three Pis that comprise C2.5; (ii) identify where SIOTI may support IOTC in progressing towards an EAFM in tuna fisheries; (iii) provide Echebastar with evidence to submit to the MSC second annual surveillance audit that the fishery can meet its PI2.5.3 condition to certification; and (iv) provide evidence to other SIOTI member fisheries that are in the MSC assessment process. Additionally, research allows the consultant to make a number of suggestions on where SIOTI could make representations to MSC on the Standard.

The scoring above, together with the outcome of the Echebastar assessment, indicate that whatever SIOTI related UoA could meet the Standard for C2.5. However, it should be borne in mind that the CAB auditors engaged in any assessment process need not accept the outcome of this study. At this stage, it would seem opportune to await the outcome of the CFTO assessment and see if this has scores for C2.5 PIs different from those gained by Echebastar.

C2.5 relates to the situation for each of the IO purse seine tuna fisheries (yellowfin, skipjack and bigeye) and SIOTI may not need related activities designed to achieve a score of 80 for each of the individual PIs.

As noted, C2.5 only relates to the impact of the UoA/UoC on the ecosystem. While cumulative fishing impacts of overlapping MSC fisheries in relation to C2.5 are not currently relevant, such impacts on ETP species, habitats and ecosystem structure and function are considered by the IOTC Working Party of Bycatch and Ecosystem to provide more integrated advice to inform the implementation of EAFM. It appears clear that EAFM will become more relevant to the management of IO tuna fisheries. Accordingly, SIOTI may wish to support basic ecosystem research to better understand and quantify the different ecological impacts of purse seine fisheries on the structure and function of marine ecosystems and inform the implementation the EAFM, with:

- Enhanced data collection in the observer programs:
  - Fish stomachs and fish samples to support research on the trophic ecology of species (tunas and non-tunas) using traditional (stomach and isotope analyses) and new techniques (DNA metabarcoding), and support the development of trophic-based indicators and trophic-based ecosystem models.
  - Size-based data for tunas and non-tunas to support the development of community size-based indicators and ecosystem models.
  - Support research on the basic biology and life history (growth, reproduction) of pelagic species (tunas and non-tunas).
- Recommend to IOTC:
  - Empirically based ecosystem indicators to monitor the ecological impacts of fisheries on the ecosystem structure and function of marine ecosystems.
  - Specialised technical workshops and joint collaborative analyses to produce ecosystem assessments.

- Ecosystem models and their use to evaluate alternative management scenarios of fishing. Ecosystem models can also assist in investigating the effect of environmental and climate-based scenarios (in combination of fishing scenarios) on the population dynamics of tuna species, and project changes in tuna distributions in response to climate change.
- A feasibility study to identify the different types of data inputs required by each ecosystem model platform (i.e. EwE, SEAPODYM, APESCOM,etc.), identify data gaps and other potential factors hindering ecosystem modelling in the IO.
- A data collection plan to support ecosystem modelling, and identify the required actions to initiate ecosystem modelling.

- Support the concept of an IOTC ocean-climate web to encourage further research and studies on the role and influence of climate and environment, including climate change, on the population dynamics, movement, abundance of main IOTC species (Marsac & Marbec 2018; Marsac & Shahifar 2019).
- Propose to IOTC adaptive management plans that respond to environmental changes and climate change.
- Support studies of the interactions between species and FADs to investigate the:
  - Fine-scale associative behaviour of tunas and non-tuna species such as silky sharks and oceanic-whitetip shark to dFADs and how these are affected by fishing area, environmental conditions and food resources.
  - FAD colonization and decolonization rates of tunas and non-tuna species using acoustic and archival tags as well as echo-sounder buoys and how these are affected by environmental conditions, food resources and FAD characteristics.
  - Effects of increasing number of FADs and FAD densities on the behaviour and biology of the species being aggregated around FAD.
- Support initiatives to use FADs as scientific platforms and as a network of autonomous observation stations to inform research.
- Support biological, life history and habitat studies of silky sharks to inform behavioural studies and bycatch mitigation techniques in FAD-associated purse seine fisheries.

In completing the work, the consultant identified a number of factors that may influence an assessment of C2.5. While, these are outside the scope of the study, and it is acknowledged that the MSC has a defined approach to monitoring and improving the Standard following robust stakeholder consultation over an extended period, the following are areas where SIOTI may like to review to provide input into the MSC process.

- The Standard could improve guidelines to facilitate the identification of what type of ecosystem impacts need to be assessed under C2.5 (Ecosystems) and what key ecosystem elements would need to be monitored to assess those impacts.
- MSC assessments of C2.5 (Ecosystems) should define upfront the type of ecosystem impact to be evaluated and the key ecosystem elements to be examined.
- A harmonized approach to assessments may be facilitated through clarification of whether the impact of dFADs on the behaviour, movement patterns and biology of ETP species should be evaluated under P2.3.1 Sic or PI2.5.1.
- The Standard could expand C2.4 (Habitats) to include both the direct impacts and indirect impacts of fishing on habitats and ensure all potential ecological impacts of fishing on habitats are covered.

- The Standard could benefit from clarification of the meaning of VME in the context of the pelagic environment and pelagic fisheries. With VME as a habitat with a *functional significance* tuna spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate could be included. As such, it could be argued that the indirect impact of FAD use on the behaviour, condition, distribution and migration of species should be assessed under C2.4 rather than C2.5.
- The issue of marine debris is becoming more relevant to the analysis of sustainability in the context of EAFM and this should be proactively reviewed by SIOTI.
- ISSF recommends further research on the potential of FADs to act as ecological traps in pelagic species. ISSF could review its best practices and actions in relation to P2 Ecosystems, through consideration of a wider range of potential types of ecosystem impact while distinguishing between C2.4 and C2.5.

Appendix 1: Terms of Reference

Background and project justification

The Marine Stewardship Council (MSC) has established a program to determine whether a fishery may be certified as sustainable. The MSC criteria defines sustainability of a fishery based on three Principles: P1 relates to the status of the stock exploited in the fishery, P2 relates to minimizing the ecosystem impacts of the fishery being assessed and P3 relates to the fishery management system.

The Echebastar IO Skipjack Tuna Purse Seine Fishery (Free school and FAD) gained the MSC certificate in November 2018. Eight binding and three non-binding conditions were raised on some of the Performance Indicators (PI) of P1, P2 and P3 (those with scores below 80) (Stokes and Rios, 2020).

PI 2.5.3 -Ecosystem Information in the MSC assessment of the Echebastar fishery achieved a score of 75. The Standard requires an adequate understanding of the elements of the ecosystem and their function, the impacts of the fishery being assessed on the broader ecosystem, the ecosystem role of the other P1 and P2 components (e.g., target species, ETP species) and the consequential impact of the fishery on those components on the broader ecosystem.

The scoring rational for scoring the PI2.5.3 found:

- *"Given that the fisheries are industrial scale, not all interactions have been investigated in the detail needed to support an ecosystem-based approach to fisheries management. Possible changes in trophic structure of pelagic oceanic ecosystems have not been investigated in sufficient detail and there is ongoing uncertainty in relation to the role of tuna fisheries in reduction of top- level predators in the IO as well as an observed increase in the prevalence of lower trophic level pelagic species (Hallier and Gaetner, 2008).*
- *"The impact of dFADs on tuna behaviour, feeding and migration, and any consequent impacts on ecosystem function, is not fully understood. Therefore, adequate information is not available on the impacts of the Unit of Assessment (UoA) on these components to allow some of the main consequences for the ecosystem to be inferred".*

Accordingly, Condition 5 of the MSC certified Echebastar fishery needs to address:

- *SIb. By the fourth annual surveillance audit, the client must provide evidence that the main impacts of the dFADs used in the UoA/UoC on these key ecosystem elements can be inferred from existing information, and some have been investigated in detail.*
- *SId. By the fourth annual surveillance audit, the client must provide evidence that there is adequate information on the impacts of the UoA on these components to allow some of the main consequences for the ecosystem to be inferred.*

Some assessments of purse seine tuna fisheries using dFADs have shown a degree of misunderstanding and uncertainty in relation to PI 2.5, with difficulties in identifying the different needs for scoring and how an UoA may meet them, and, if required, respond to any condition (e.g., Stokes and Rios 2020, Sieben *et al* 2019). There have been also some difficulties and confusion on how ecosystems and habitat impacts (C2.4 and C2.5) may be related, and the consequent cross cutting issues when scoring them in the context of purse seine tuna fisheries with dFADs (Juan-Jordá 2019).

Moreover, in relation to C2.5 two recent CDRs for MSC full assessments have rationales that differ to the Echebastar MSC assessment.

- CFTO: PI 2.5.3 regarding the three scoring issues (a) Information Quality (b) Investigation of UoA Impacts and (d) Information Relevance (Stokes and Rios 2020, Sieben *et al* 2019).
- AGAC: PI 2.5.1 Prospective scoring (90 vs Echebastar 80) (Akroyd *et al* 2020).

In responding to the need to (i) clarify the approach to C2.5 (ii) harmonise scoring and rationales between MSC certified fisheries; and (iii) advise other prospective MSC assessments by SIOTI producer members, SIOTI proposes the following study project and tasks.

Objectives

The objectives of the study are:

- Confirm the requirements to meet the MSC standard for Component 2.5.
- Identify the key ecosystem components that should be considered by UoA and UoC for purse seine dFAD fisheries.
- Assess the current understanding of potential impacts of those UoA / UoC on key ecosystem components, taking into consideration generic ecosystem research, other fishing regions, and existing MSC assessments.
- Advise SIOTI of any activities required to support SIOTI related UoA to meet the MSC standard at PI2.5.1 and PI2.5.3 and the implications for any client action plan related to conditions to certification defined for C2.5, bearing in mind that this element of the MSC standard refers to the impact of the UoA/UoC.
- Consider the potential issues for C2.5 related to other fishing methods i.e., Anchored FADs and fishing on logs.

Scope of work

- **Task 1**. Review C2.5 of the MSC Standard and provide an opinion on how this should be applied to an UoA for the purse seine tuna fishery using dFADs.
- **Task 2**. Identify and define the key ecosystem elements that may be impacted by the purse seine tuna dFAD fishery, taking into account, for example, the potential relevance of the ecological trap hypothesis on species other than tunas e.g., silky sharks.
- **Task 3**. Analyse the information available (including on-going research) to provide evidence on the extent to which the impact of dFADs on key ecosystem elements may be inferred (bearing in mind that sources are not restricted to the IO tuna fishery).
- **Task 4**. Identify and describe those impacts that have been investigated in detail (bearing in mind that sources are not restricted to the IO tuna fishery).
- **Task 5**. Based on current understanding and completed research, assess whether or not there is adequate information on the impact of a UoA (identify any potential differences due to any variation in the number of vessels comprising the UoA) on individual key ecosystem elements that allow some of the main consequences for the ecosystem to be inferred.
- **Task 6**. Based on the findings, provide a shadow scoring for PI 2.5.1 and PI 2.5.3.
- **Task 7**. Recommend any further actions that may be needed to allow Echebastar and other SIOTI related UoA to score 90 for PI 2.5.1 SIa and 80 for all PI 2.5.3 SIs by end-2001.

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