



**HAL**  
open science

## The challenge of assessing the effects of drifting fish aggregating devices on the behaviour and biology of tropical tuna

Amaël Dupaix, Frédéric Ménard, John D Filmalter, Yannick Baidai, Nathalie Bodin, Manuela Capello, Emmanuel Chassot, Hervé Demarcq, Jean-Louis Deneubourg, Alain Fonteneau, et al.

### ► To cite this version:

Amaël Dupaix, Frédéric Ménard, John D Filmalter, Yannick Baidai, Nathalie Bodin, et al.. The challenge of assessing the effects of drifting fish aggregating devices on the behaviour and biology of tropical tuna. 2023. hal-04047298v3

**HAL Id: hal-04047298**

**<https://hal.science/hal-04047298v3>**

Preprint submitted on 17 Oct 2023 (v3), last revised 20 Dec 2023 (v4)

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

1 **Title 1: The challenge of assessing the effects of drifting fish aggregating devices on**  
2 **the behaviour and biology of tropical tuna**

3 **Title 2: Effects of drifting fish aggregating devices on the biology and behaviour of**  
4 **tropical tuna**

5

6 **Running title:** Effects of DFADs on tropical tuna (33 characters including space < 40)

7

8 **Authors:** Dupaix Amaël<sup>1</sup>, Ménard Frédéric<sup>2</sup>, Filmalter John D<sup>3</sup>, Baidai Yannick<sup>4</sup>, Bodin  
9 Nathalie<sup>5,6</sup>, Capello Manuela<sup>1</sup>, Chassot Emmanuel<sup>7</sup>, Demarcq Hervé<sup>1</sup>, Deneubourg Jean-  
10 Louis<sup>8</sup>, Fonteneau Alain<sup>9</sup>, Forget Fabien<sup>1</sup>, Forrestal Francesca<sup>10</sup>, Gaertner Daniel<sup>1</sup>, Hall  
11 Martin<sup>11</sup>, Holland Kim N.<sup>12</sup>, Itano David<sup>13</sup>, Kaplan David Michael<sup>1</sup>, Lopez Jon<sup>11</sup>, Marsac  
12 Francis<sup>1</sup>, Maufroy Alexandra<sup>14</sup>, Moreno Gala<sup>15</sup>, Muir Jeff A.<sup>12</sup>, Murua Hilario<sup>15</sup>, Roa-Pascuali  
13 Liliana<sup>16</sup>, Pérez Géraldine<sup>17</sup>, Restrepo Victor<sup>15</sup>, Robert Marianne<sup>18</sup>, Schaefer Kurt M.<sup>11</sup>,  
14 Sempo Grégory<sup>19</sup>, Soria Marc<sup>1</sup>, Dagorn Laurent<sup>1</sup>

15

16 **Corresponding Author:** Amaël Dupaix, amael.dupaix@ird.fr

17

18 **Affiliations:**

19 <sup>1</sup>: MARBEC, Univ. Montpellier, CNRS, Ifremer, IRD, INRAE, Sète, France

20 <sup>2</sup>: Aix Marseille Univ., Université de Toulon, CNRS, IRD, Mediterranean Institute of  
21 Oceanography, Marseille, France

22 <sup>3</sup>: South African Institute for Aquatic Biodiversity, Grahamstown, South Africa

23 <sup>4</sup>: African Marine Expertise, Abidjan, Ivory Coast

24 <sup>5</sup>: Seychelles Fishing Authority (SFA), Fishing Port, Victoria P.O. Box 449, Mahé, Seychelles

25 <sup>6</sup>: Sustainable Ocean Seychelles, BeauBelle, Mahé, Seychelles

26 <sup>7</sup>: Indian Ocean Tuna Commission (IOTC), C/O IOTC Secretariat, Blend Seychelles, Victoria,  
27 Mahé, Seychelles

28 <sup>8</sup>: CENOLI, Université Libre de Bruxelles (ULB), Bruxelles, Belgium

- 29 <sup>9</sup>: Consultant, Saint-Malo, France
- 30 <sup>10</sup>: Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic  
31 and Atmospheric Administration (NOAA)
- 32 <sup>11</sup>: Inter-American Tropical Tuna Commission, La Jolla, CA 92037, USA
- 33 <sup>12</sup>: Hawaii Institute of Marine Biology, University of Hawaii at Manoa, Kaneohe, HI, United  
34 States of America
- 35 <sup>13</sup>: Opah Consulting, Honolulu, HI, United States of America
- 36 <sup>14</sup>: Organisation des Producteurs de thon congelé et surgelé (ORTHONGEL), Concarneau,  
37 France
- 38 <sup>15</sup>: International Seafood Sustainability Foundation, Pittsburg, PA 15201-1820, USA
- 39 <sup>16</sup>: Collecte Localisation Satellites, Ramonville Saint-Agne, France
- 40 <sup>17</sup>: Institut océanographique Paul Ricard, Île des Embiez - 83140 Six-Fours-les-Plages,  
41 France
- 42 <sup>18</sup>: UMR DECOD (Ecosystem Dynamics and Sustainability), IFREMER, INRAE, Institut Agro -  
43 Agrocampus Ouest, 8 rue François Toullec, 56100 Lorient, France
- 44 <sup>19</sup>: Faculté de Médecine, Université libre de Bruxelles (ULB), Bruxelles, Belgium

45 **Abstract (247 words < 250)**

46 Fishers have intensively used drifting fish aggregating devices (DFADs) over the last three  
47 decades to facilitate their catch of tropical tunas. DFADs increase purse-seine efficiency,  
48 potentially increasing tuna fishing mortality. They could also have indirect impacts (unrelated  
49 with fishing mortality) and assessing the consequences of their presence at sea on tuna  
50 populations is a challenge. The use of DFADs results in a major increase in the number of  
51 floating objects, which are spatially heterogeneous at sea. To date, no converging scientific  
52 results exist regarding the indirect effects of DFADs on the large-scale movements and  
53 behaviour of tuna, mainly due to the difficulty of disentangling the respective roles of DFADs  
54 and environmental factors. Some biological indices show that tuna condition is lower when  
55 associated to a floating object than in a free-swimming school. However, it is not clear  
56 whether this is the cause or the consequence of the association, nor if it has long-term  
57 effects on individuals' fitness. Further scientific progress require (i) the collection of time  
58 series of indicators to monitor habitat change, individual behaviour, individual fitness and  
59 population dynamics, and (ii) experimental studies to identify the underlying behavioural and  
60 biological processes involved in associative behaviour. The extent of the modification of the  
61 surface habitat by the massive deployment of DFADs and the current uncertainty of the  
62 possible long-term consequences on the individual fitness and dynamics of tuna populations  
63 argue for the need for increased awareness of this issue by Regional Fisheries Management  
64 Organisations regulating tuna fishing.

65

66 **Keywords** (6 max): DFAD, ecological effects, ecological trap, fish behaviour, fisheries  
67 management, tuna

68

69

70	<b>Table of contents</b>
71	
72	<b>Introduction</b>
73	<b>How much do DFADs change the habitat of tropical tunas?</b>
74	<b>Do DFADs modify the migration and the schooling behaviour of tropical tunas?</b>
75	<i>Effects on individual large-scale movements</i>
76	<i>Effects on individual fine-scale movements</i>
77	<i>Effects on schooling behaviour</i>
78	<b>Do DFADs modify the life-history parameters of tropical tunas?</b>
79	<i>Effects on feeding</i>
80	<i>Effects on body condition</i>
81	<i>Effects on reproduction and growth</i>
82	<b>What are the scientific challenges to fill the knowledge gaps?</b>
83	<b>Conclusion</b>
84	<b>Acknowledgements</b>
85	<b>Data availability statement</b>
86	<b>References</b>
87	<b>Tables</b>
88	<b>Figures</b>
89	
90	

## 91 Introduction

92 Many fish species are known to associate with floating objects (FOBs; Castro et al., 2002;  
93 Fréon & Dagorn, 2000), with the first known descriptions of fishers exploiting these  
94 associations dating from 200 AD in the Mediterranean Sea by the Roman author Oppian  
95 (cited in Taquet, 2013). In particular, the use of FOBs to facilitate the capture of tropical  
96 tunas (skipjack SKJ – *Katsuwonus pelamis*; yellowfin YFT – *Thunnus albacares*; and bigeye  
97 BET – *T. obesus*), has undergone rapid expansion in recent decades, as a result of the  
98 growing importance of these floating structures to the strategy and efficiency of tropical tuna  
99 purse seine fleets (Dagorn et al., 2012; Fonteneau et al., 2000, 2013; Leroy et al., 2013;  
100 Miyake et al., 2010). Since the onset of the tropical tuna purse seine fishery, fishers took  
101 advantage of the associative behaviour of tunas with floating objects and actively searched  
102 for natural floating objects (NLOGs) to improve their catches (Greenblatt, 1979 ; Hallier and  
103 Parajua, 1999 ; Scott et al. 1999). Towards the end of the 1980s, fishers began to build and  
104 deploy man-made drifting fish aggregating devices (DFADs), and to attach radio buoys to  
105 locate them (Ariz et al., 1999 ; Hallier and Parajua, 1999 ; Hall et al. 1992 ; Scott et al. 1999 ;  
106 Lopez et al., 2014; Marsac et al., 2014; Moreno et al., 2007; Morón, 2001; Stéquert &  
107 Marsac, 1986). DFADs are commonly composed of a floating structure (such as a bamboo or  
108 metal raft with buoyancy provided by corks, etc.) and a submerged structure (made of ropes,  
109 old netting, canvas, weights, etc.). During the last two decades, radio buoys have been  
110 replaced by GPS buoys communicating via satellite directly with fishing vessels. In the last  
111 decade (2010-2020), most DFADs have been equipped with echo-sounder buoys, providing  
112 estimates of aggregated biomass (Lopez et al., 2014). Some fleets also use supply vessels  
113 to maintain their DFAD array and to inform the fishing vessels of tuna aggregations  
114 (Arrizabalaga et al., 2001; Ramos et al., 2013). DFADs represent very efficient fishing tools  
115 that increase the catchability of tunas, leading purse-seine fleets to target preferentially  
116 associated schools and expanding their fishing grounds (Lopez et al. 2014, Fonteneau et al.  
117 2015, Lennert-Cody et al. 2019).

118 Over time, given the growing contribution of purse seine fleets to world tuna catches and the  
119 increasing importance of DFAD fishing in the strategy of purse seine fleets, managing

120 DFADs has become a priority for all tuna Regional Fishery Management Organisations  
121 (tRFMOs). In this paper we will use “operational” or “active” buoys to designate buoys  
122 attached to a FOB that are tracked by one or several purse seine fishing vessel(s). Tuna  
123 RFMOs set limits of the number of operational buoys (with the very first limit by the IOTC,  
124 Indian Ocean Tuna Commission, in 2015) to mitigate the different risks induced by the  
125 deployment and use of DFADs (most recent resolutions: IOTC Res 19/02, ICCAT Rec 22-01,  
126 IATTC Res C-21-04, WCPFC CMM 2021-01). Fishing at FOBs was demonstrated to  
127 increase by-catch rates, compared to fishing on free-swimming schools (Amandé et al. 2012,  
128 Escalle et al. 2018), and to increase the proportion of small BET and YFT (IOTC 2022). As a  
129 consequence, spawning capacity and yield per recruit of BET and YFT populations are  
130 reduced worldwide by purse-seine vessels setting on DFADs and catching small individuals  
131 of these two species (Davies et al. 2014).

132 Other major DFAD-related measures concern the design of these objects, following the  
133 discovery of sharks getting entangled in the netting composing the structure of DFADs  
134 (Filmlalter et al. 2013). Limiting the pollution induced by DFADs in the ocean is also in front of  
135 the agendas of tRFMOs, after realizing the large quantity of plastic used in DFADs and the  
136 large numbers of DFAD beaching events in sensitive coastal ecosystems (Escalle et al.  
137 2019, Imzilen et al. 2021, 2022). However, other impacts on tuna populations (unrelated to  
138 fishery vulnerability) and ecosystems may be induced by the increased presence of DFADs  
139 in their habitat (Marsac et al. 2000, Bromhead et al. 2003, Hallier & Gaertner 2008). Despite  
140 the limits on operational buoys, DFADs number in the water has increased (Dagorn et al.  
141 2013a, Maufroy et al. 2017, Imzilen et al. 2021, Dupaix et al. 2021). As such, while logs and  
142 branches have always been components of the habitat of tropical tunas (originating from  
143 rivers, mangroves or shorelines), the massive use of man-made DFADs has changed their  
144 habitat, which could have numerous consequences on tropical tuna’s fitness, resulting in  
145 population-level impacts.

146 Changing a habitat can positively or negatively impact the ecology of wild animals inhabiting  
147 it. For example, artificial habitats could benefit some reef species (Lee et al. 2018).  
148 Contrarily, alterations could also reduce habitat quality, e.g. by reducing the number of

149 shelters or nests for some species, or by decreasing their food resources (often through the  
150 alteration of the habitat of these resources themselves, Mullu 2016). In some cases, animals  
151 are misled by cues that were previously correlated with the habitat quality but no longer are,  
152 due to anthropogenic influences (Sherley et al. 2017, Swearer et al. 2021). Such impacts  
153 form the basis of the ecological trap theory and result in the preferential selection of low-  
154 quality habitats by animals, when better alternatives exist (Battin, 2004; Schlaepfer et al.,  
155 2002). It is worth noting that, depending on the definition, an ecological trap can occur  
156 without any anthropogenic influence (Robertson & Hutto, 2006; Swearer et al., 2021; Teske  
157 et al., 2021). In this paper, we will consider that ecological traps occur because of a sudden  
158 anthropogenic change in the environment, i.e. in the case of tropical tuna, the modification of  
159 their surface habitat by the increased deployment of DFADs (Gilroy & Sutherland, 2007;  
160 Hallier & Gaertner, 2008; Schlaepfer et al., 2002). While this theory has been proposed  
161 regularly in the face of anthropogenic environmental modifications and their impacts on  
162 various species, few studies have empirically demonstrated the existence of such traps  
163 (Battin, 2004; Swearer et al., 2021).

164 Noting the increasing number of floating objects being deployed by fishers during the 1990s,  
165 some scientists hypothesized that the increase in the number of DFADs could lead to an  
166 ecological trap, altering the ecological value of floating objects for tropical tunas associated  
167 to DFADs (Marsac et al., 2000). This hypothesis is not the only potential indirect impact of  
168 DFADs and it is hypothesized that large numbers of DFADs may alter certain biological  
169 characteristics of epipelagic populations associated with them: migration, schooling  
170 behaviour, growth, fish condition and bioenergetics, predation and natural mortality (Figures  
171 1 & 2). TRFMOs primarily focus on developing management schemes to address the known  
172 effects of DFADs on catches (particularly of small YFT and BET, as well as bycatch) or their  
173 stranding on coasts. Through the increase of FOB density they induce, DFADs could also  
174 impact tropical tuna natural mortality and reproductive potential, hence, altering their  
175 individual fitness which could have population-level consequences. These indirect impacts  
176 could act as compounding factors and worsen the increase of fishing mortality induced by  
177 DFADs. Hence, there is a need to assess whether DFADs can alter the life history



178 parameters and behaviour of tunas. This will help to determine the magnitude of indirect  
179 impacts relative to direct ones and to manage the number of DFADs deployed at sea if  
180 negative indirect impacts are suspected or demonstrated.

181 Almost 20 years ago, Dempster & Taquet (2004) made a systematic review of the published  
182 literature on FADs and concluded that further research should assess the use of DFADs by  
183 pelagic species, the mechanisms underlying their associative behaviour and the ecological  
184 consequences of the presence of DFADs at sea on pelagic fish stocks. Since then, several  
185 papers reviewed existing evidence and/or proposed future research directions to address the  
186 impacts of DFADs on tropical tuna (Dagorn et al. 2013b, Evans et al. 2015, Davies et al.  
187 2014, Fonteneau et al. 2015, Leroy et al. 2013, Taquet 2013). Yet, most of these papers,  
188 except Taquet (2013), addressed these impacts at a regional scale and all were mainly  
189 focussing on the direct impacts of DFADs (induced by an increase of fishing mortality), even  
190 though they mentioned potential indirect impacts (not related to fishing mortality increase).  
191 The objective and originality of this paper is to review the current knowledge on the impacts  
192 of DFADs on the ecology and life history traits of tropical tuna, focussing only on the indirect  
193 effects (consequences of fishing on DFADs are not addressed here). This particular question  
194 has generated a global scientific debate for years, precluding management bodies from  
195 having a complete and synthetic view of the current knowledge. The extent of these indirect  
196 impacts is unknown and determining if they act as compounding factors on the increase of  
197 fishing mortality induced by DFADs is urgent. An in-depth literature review provides an  
198 overview of the state of the art in this area, identifies knowledge gaps, and proposes future  
199 research priorities. This paper is structured around four major questions:

200 i) How much do DFADs change the habitat of tropical tunas?

201 ii) Do DFADs modify the migration and the schooling behaviour of tropical tunas?

202 iii) Do DFADs affect the life history parameters of tropical tunas?

203 iv) What are the scientific challenges to fill the knowledge gaps?

204 **How much do DFADs change the habitat of tropical tunas?**

205 Tropical tuna are circumtropical pelagic fish, preferring relatively warm and stratified waters,  
206 with larvae preferring waters above 24°C (Artetxe-Arrate et al., 2021). SKJ, YFT and BET are  
207 considered epipelagic species which also exploit the mesopelagic zone, especially during the  
208 day when searching for deep scattering prey organisms (Schaefer et al. 2009). Whereas  
209 small and large BET are capable of spending long periods of time in the mesopelagic zone,  
210 due to their thermal physiology, SKJ and YFT are only able to remain for brief periods of time  
211 when exhibiting repetitive bounce diving behaviour. Hence, tropical tuna have distinct  
212 ecological niches at different stages of their life-history (Artetxe-Arrate et al., 2021). Tuna  
213 habitat can be defined as the surface and sub-surface ocean waters, with all the abiotic  
214 (temperature, dissolved oxygen, etc.) and biotic (prey, competitors, etc.) parameters  
215 important for their biological functions. Among the components of tuna habitats, floating  
216 objects represent very peculiar features. They represent physical discontinuities that tuna are  
217 known to associate with, at least at given stages of their life-history (mainly adult SKJ, small  
218 YFT and BET). Human activities (logging, coastal development, shipping, etc.) modified the  
219 number of floating objects at sea, in some cases even before modern purse-seine tuna  
220 fishing began (Caddy & Majkowski, 1996; Thiel & Gutow, 2005). Some of these activities  
221 may have consistently increased (coastal development, shipping), whereas others, such as  
222 logging, may have varied due to increased global trade and subsequent deforestation of  
223 some areas (Caddy & Majkowski, 1996). In addition, environmental changes also affect the  
224 production and movement of floating objects (e.g. floods, El Niño events, tsunamis), with  
225 global warming supposed to increase the frequency of extreme events. In recent years, the  
226 increasing use of DFADs by fishers raised several questions about the sustainability of this  
227 practice. The primary concern is the increase in fishing efficiency and mortality induced by  
228 DFAD fishing (Dagorn et al. 2013b, IOTC 2022, Pons et al. 2023). However, the increase of  
229 the number of floating objects could also induce indirect impacts on tuna behaviour and life  
230 history parameters, which are more challenging to address. In the current framework of the  
231 ecosystem approach to fisheries (Pikitch et al. 2004), the assessment and management of  
232 these impacts is fundamental.

233 Two types of floating objects (referred to as FOBs) are commonly considered: (i) man-made  
234 FADs (which can be drifting, DFADs, or anchored, AFADs) and (ii) natural objects (trees,  
235 branches, etc., referred to as NLOGs) or artificial objects (wreckage, nets, washing  
236 machines, etc., referred to as ALOGs) that are not deployed for the specific purpose of  
237 fishing (collectively called LOGs) (Gaertner et al., 2018). Fishers fish on DFADs and LOGs  
238 and can equip any of those objects with a satellite-tracking buoy, becoming therefore a  
239 fishing tool monitored by a fishing vessel. For the particular question of habitat change  
240 addressed in this study, only DFADs – which are the dominant type of man-made floating  
241 objects used in the industrial purse seine fishery (Dagorn et al. 2013a, Maufroy et al. 2017,  
242 Dupaix et al. 2021) – are considered and not AFADs.

243 DFADs increase the density of FOBs. This change could impact tuna associative behaviour,  
244 tuna migrations, tuna fitness, then potentially resulting in an increase of tuna natural mortality  
245 and a decrease of reproductive potential and, hence, impacts on tuna populations. Changes  
246 in the “FOB component” of habitat due to DFADs can be assessed by estimating and  
247 comparing densities of objects (with information on their nature: LOGs or DFADs) and  
248 distance between objects (nearest neighbour), with both parameters being closely related.  
249 These parameters depend upon the rates at which DFADs are added or removed from the  
250 ocean (by sinking, beaching or retrieved by humans), as well as their drift. For every oceanic  
251 spatio-temporal unit (e.g. region and season), comparing these parameters with those of  
252 natural floating objects and for all types together (natural and artificial) is challenging, the  
253 primary concern being to identify the origin of the floating object.

254 The number of DFADs have regularly increased (Maufroy et al. 2017), but it is necessary to  
255 put this in perspective with respect to all floating objects. Using data from observers onboard  
256 tuna purse seine vessels in the Indian Ocean (IO), noting all FOBs encountered when the  
257 vessel cruises, Dupaix et al. (2021) highlighted a drastic increase in the total number of  
258 floating objects in the western IO, from 2006 to 2018, with multiplication factors greater than  
259 2 in every region and reaching as high as 60 in some areas (e.g. Somali area). The entire  
260 western IO is affected, with DFADs comprising over 85% of the total FOBs and DFADs  
261 contributing to reduce the distances between floating objects (mean distances between

262 DFADs and between NLOGs of 37 km and 89 km, respectively, in 2014-2018). The impact of  
263 DFADs on tuna habitat reducing the distance between FOBs was observed in the study both  
264 when considering all DFADs or only randomly encountered DFADs (objects which do not  
265 belong to the vessel or its fishing company), to account for a potential sampling bias. Phillips  
266 et al. (2019a), using data from 2016 and 2017 and Lagrangian simulations in the Western  
267 and Central Pacific Ocean (WCPO), also showed an increase in FOB densities induced by  
268 DFAD deployments, and observed a shift of the area with the highest FOB densities, from  
269 the North-Eastern area of the Bismark Sea to the Tuvalu archipelago. Unfortunately, to our  
270 knowledge, no similar detailed study has been conducted in the other oceans, precluding  
271 from estimating the extent of the change of the habitat of tunas due to the addition of new  
272 floating objects globally.

273 Most of the management effort by tRFMOs is focused on the monitoring and control of  
274 satellite-tracked buoys attached to floating objects (either to DFADs or to LOGs), emitting  
275 positions (and other variables) to vessels and qualified as operational buoys, as this variable  
276 is strongly related to fishing effort. This also explains why most scientific studies prioritized  
277 the estimate of operational buoys rather than the number of DFADs in the ocean (Table 1).  
278 Currently, all tRFMOs have implemented a limit on the instantaneous number of operational  
279 satellite buoys per vessel, and, except in the Atlantic Ocean (AO), limited the re-activation of  
280 buoys while at sea, but only the IOTC has limited the number of buoys purchased and in  
281 stock per year, per vessel (IOTC Res 19/02, ICCAT Rec 22-01, IATTC Res C-21-04,  
282 WCPFC CMM 2021-01). This clearly reflects a lack of concerted action worldwide to limit the  
283 number of new floating objects deployed in the oceans. Even under the limit of active DFADs  
284 at sea per vessel, the actual total numbers of DFADs in the ocean could have increased. So  
285 far, few studies have produced estimates of the total number of DFADs deployed annually,  
286 with estimations providing a range of 81,000 to 121,000 deployments worldwide, but these  
287 global estimates were made a decade ago (Baske et al., 2012; Gershman et al., 2015; Scott  
288 & Lopez, 2014). As a comparison, AFADs seem to be less numerous worldwide (13,000  
289 AFADs estimated in Scott & Lopez 2014), although there may be few areas with very high

290 densities of AFADs, such as Indonesia (5,000-10,000, Proctor et al. 2019), the Philippines or  
291 Papua New Guinea.

292 In practice, despite efforts by tRFMOs to require the submission of DFAD data, accurately  
293 determining a simple indicator such as the total number of DFADs that are drifting in the  
294 world's oceans is a major challenge. The easiest way would be to monitor the number of  
295 deployments through logbooks or onboard observers or set up a FAD register (see Res  
296 23/02 of the IOTC). The number of operational buoys does not correspond to the number of  
297 DFADs in the water (and/or deployed) as some buoys can be attached to LOGs, can be  
298 deactivated, and some DFADs may lack positional trackers, but it can be used as a proxy to  
299 illustrate the trend in numbers. Therefore, as the number of operational buoys does not  
300 effectively limit DFAD deployments, the number of DFADs in the water and/or deployments  
301 could be larger than the limits adopted by the tRFMOs. Under the assumption that the  
302 number of natural floating objects remains relatively constant, the increasing number of  
303 electronic buoys used reflects an increase of the number of FOBs. In recent years, DFAD  
304 deployments were stable in the WCPO (2011-2019; Escalle et al. 2020), decreased in the IO  
305 (2016-2021; IOTC, 2022), increased in the Eastern Pacific Ocean (EPO, 2015-2020; Lopez  
306 et al. 2021) and buoy deployments increased in the AO (2007-2013; Maufroy et al. 2017).  
307 Hence, a characterisation of DFAD deployment trends at the global scale is needed.  
308 However, the clear trend in the number of DFAD sets or DFAD catches (Floch et al., 2019;  
309 FIRMS Global Tuna Atlas cited in IOTC, 2021; Restrepo et al., 2017) suggests that DFAD  
310 deployment has also increased.

### 311 **Do DFADs modify the migration and the schooling behaviour of tropical tunas?**

312 DFADs may affect both the movements of tunas and their schooling behaviour. Large-scale  
313 movements of tunas can be impacted in the following two ways: (i) DFADs could cause tunas  
314 to relocate to new areas and (ii) they could increase residence times in some areas. If  
315 DFADs were to have an impact on tuna's large-scale movements, it could increase their  
316 natural mortality by retaining or relocating them in unsuitable areas or disturbing their  
317 migration (Marsac et al. 2000). Although we are currently not able to quantify, and even

318 demonstrate, such impacts, they could result in population-scale effects. Ideally, the best  
319 approach for investigating such potential effects would be to compare the large-scale  
320 movement patterns of tunas before and after the period in which the increase of DFAD  
321 numbers occurred (i.e. before or after the 1990's). To our knowledge, historical data to  
322 assess large-scale movement patterns before fishers started to massively deploy DFADs,  
323 necessary for this type of analysis, exist only in the WCPO (Kim 2015) and in the EAO  
324 (Cayré et al. 1986) and we do not know of any long-term study that compared movement  
325 patterns before and after DFAD use increased.

### 326 *Effects on individual large-scale movements*

327 Wang et al. (2014) found that the spatial dynamics of free-swimming school sets in the  
328 WCPO were influenced by the onset of El Niño Southern Oscillation (ENSO) events, while  
329 these events had no effects on the location of floating-object-associated school sets. This  
330 result does not allow us to conclude on the impact of DFADs on population movements, as  
331 catch data reflects the movements of the available catchable portion of the stocks and the  
332 catchability of different set types (e.g. DFAD sets catching smaller individuals than the free-  
333 school sets), and not the true movements of fish.

334 Hallier & Gaertner (2008) analysed conventional tagging data of SKJ and YFT in the Eastern  
335 Atlantic Ocean (EAO). Different migratory directional patterns and displacement rates were  
336 observed between fish recaptures associated with DFADs and those in free-swimming  
337 schools. Displacement rates were significantly larger for both YFT and SKJ recaptured in  
338 association with DFADs (13 and 15 nm/day, respectively) than those recaptured in free-  
339 swimming schools (3 and 4.5 nm/day, respectively), which suggests that DFADs could  
340 relocate tunas to new areas. In the IO, Stehfest and Dagorn (2010) found similar results for  
341 SKJ, YFT and BET, but with lower displacement rates differences than in the AO. Hallier and  
342 Gaertner (2008) interpreted these results as indicating significant modifications of migratory  
343 patterns due to associations with DFADs, suggesting an influence of DFAD association  
344 strong-enough to disturb tropical tuna migratory patterns. However, Stehfest and Dagorn  
345 (2010) argue that it could only reflect an artefact of the non-uniform distribution of DFAD

346 fishing. Also, authors of both studies agree that school type at recapture might not be  
347 representative of the associative history of individuals before their recapture. Using an  
348 advection-diffusion model, Kim (2015) also showed that including a DFAD attraction  
349 component to the model better fitted SKJ tagging data in the WCPO, suggesting an effect of  
350 DFADs on SKJ migratory patterns. Comparing DFAD induced movements in the 2000s with  
351 those in the 1990s, they showed that the rising DFAD density increased this modification of  
352 migration patterns. These studies were the only ones to assess differences of movement  
353 patterns induced by DFADs and, due to species and ocean differences, more studies would  
354 be needed to interpret these results at a global scale.

355 DFADs potential to modify large-scale movements of tunas can be investigated through  
356 archival tags by comparing tuna movements with the general drift patterns of DFADs. In the  
357 equatorial EPO, evaluation of archival tag data sets from 96 BET (54-159 cm in length, 1-5.5  
358 years of age) tagged between 2000 – 2005 (Schaefer et al., 2009; Schaefer & Fuller, 2010)  
359 did not support the hypothesis that the most probable BET tracks were related to the general  
360 drift patterns of DFADs. This suggests that the large-scale spatial dynamics of BET are not  
361 strongly influenced by DFADs at the densities and conditions found in the EPO. However, in  
362 the Central Pacific Ocean (CPO), a predominantly eastward extensive dispersion of BET  
363 tagged with conventional tags and archival tags was observed (Schaefer et al., 2015). The  
364 authors explain the strong regional fidelity of BET in the equatorial EPO by the high  
365 concentration of food, leading to their residence and retention in that area. In the equatorial  
366 CPO, the strong eastward-flowing North equatorial countercurrent and BET searching for  
367 higher prey concentrations could explain the predominantly eastward dispersion of BET.

### 368 *Effects on individual fine-scale movements*

369 The possibility of DFADs influencing tuna movements could be evaluated by determining the  
370 impact of DFADs on tuna's fine-scale movements. First, if DFADs increase the percentage of  
371 the time tuna spend associated with floating objects, it will increase their availability to  
372 fishers. It can therefore have a direct impact by increasing catchability and fishing mortality.  
373 In addition, a modification of fine-scale tuna movements could also result in indirect

374 population-scale impacts by inducing larger-scale movement changes. In this section, we  
375 focus on the modifications of tuna fine-scale movements induced by DFADs and on how  
376 these changes could result in large-scale movement modifications. Fine-scale movements  
377 can be assessed through the measurement of the time tuna spend associated with DFADs  
378 and the time they spend unassociated (or between two DFAD associations). It could be  
379 considered that the longer tunas remain associated with DFADs, the larger the influence  
380 DFADs could have on their large-scale movements.

381 Acoustic tags and archival tags (only when a species exhibits a distinct vertical behaviour  
382 when associating with a floating object, as observed for BET or sometimes YFT) have been  
383 used by scientists to measure these parameters (Table 2). Passive acoustic tagging studies  
384 on DFADs revealed that the majority of residence times of tunas (i.e. continuous periods of  
385 time spent associated with a given DFAD) were of a few days. Mean values ranged from 0.2  
386 to 4.6 days for SKJ (Dagorn et al., 2007; Govinden et al., 2021; Matsumoto et al., 2014,  
387 2016), from 1.0 to 6.6 days for YFT and 1.4 to 10 days for BET (Dagorn et al., 2007;  
388 Govinden et al., 2021; Matsumoto et al., 2016, Phillips et al. 2019b). Long associations,  
389 however, have been observed on rare occasions – e.g. 27 days for YFT in the IO (Govinden  
390 et al., 2021) and up to 18, 50 and 30 days for SKJ, YFT and BET respectively, in the WCPO  
391 (Phillips et al. 2017, Phillips et al. 2019b). A recent study in the EAO (Tolotti et al., 2020)  
392 reported significantly larger mean residence times for the three tuna species, from 9 days  
393 (SKJ) to 19 days (YFT) and 25 days (BET), with record values of 55 days and 600 km  
394 travelled associated to a DFAD for both BET and YFT.

395 These studies suggest that residence times at a single DFAD vary between oceanic regions  
396 and species. Without more studies, it is difficult to assess whether the long DFAD  
397 associations observed are restricted to specific areas and time periods, or if they can often  
398 occur. In fact, even short residence times at single DFADs as those observed in the Indian  
399 and Pacific oceans do not prove that arrays of DFADs cannot influence large-scale  
400 movements. In an array of DFADs, a tuna can “switch” from one DFAD to a neighbouring  
401 one, which could retain it in the array. It is therefore important to also measure the time tunas  
402 spend between two associations (or unassociated), or in other words, the total percentage of



403 time a tuna spends associated over long periods. This variable is likely to depend on the  
404 density of all floating objects in the area. So far, very few durations between two DFAD  
405 associations have been measured using acoustic tags because it is difficult to locate and  
406 exhaustively instrument with acoustic receivers all DFADs in an area.

407 In the WCPO, 25 BET, 6 YFT and 2 SKJ displayed “homing” behaviour by returning to the  
408 same DFAD with absences greater than a day (Phillips et al. 2019b). Most of these absences  
409 were short for BET (median: 3.2 days) and longer for YFT (median: 10.5 days) but with a low  
410 sample size not allowing to be conclusive. In the other tropical oceans, even fewer tunas  
411 were observed performing such homing behaviour: one BET in the AO (out of 23 tagged fish,  
412 Tolotti et al., 2020), one YFT and two SKJ in the IO (out of 31 and 17 tagged fish  
413 respectively, Govinden et al., 2021), and these absences lasted less than two days.

414 Because BET and sometimes YFT exhibit different vertical behaviour patterns when  
415 associated or non-associated with floating objects (Holland and Brill 1990, Abascal et al.  
416 2018), archival tags have been used to assess residence times at and between floating  
417 objects, and therefore percentage of days associated with floating objects, without the need  
418 to instrument all objects with acoustic receivers. Using satellite archival tagging data where  
419 individual BET tracks could be recorded over several months or even years, the percentage  
420 of time associated with floating objects was estimated to be between 4 % and 17 %  
421 depending on the size of the fish and the oceanic region (Fuller et al., 2015; Phillips et al.,  
422 2017; Schaefer & Fuller, 2010, Leroy et al. 2013, Schaefer & Fuller 2002). Associative and  
423 non-associative behaviour with floating objects have also been described with archival tags  
424 for YFT (Phillips et al., 2017; Schaefer et al., 2009; Schaefer & Fuller, 2013, Leroy et al.  
425 2013), with estimates of the percentage of time spent associated with floating objects  
426 between 10% and 23%. These percentages are much lower than those estimated from  
427 acoustic telemetry data (e.g. 75 % for small BET based on the measurements in Phillips, et  
428 al. 2019b).

429 This inconsistency between studies using different tagging methods could result from the  
430 size of tagged individuals or the way the percentage of time spent by tuna associated and

431 non-associated is calculated. Individuals monitored with archival tags were generally larger  
432 (fork length: 50-146 cm YFT and 46-102 cm BET in Phillips et al. 2017, 51-134 cm BET in  
433 Fuller et al. 2015, 88-134 cm BET in Schaefer & Fuller 2002, 54-159 cm BET in Schaefer &  
434 Fuller 2010) than those marked with passive acoustic tags (38-90 cm BET in Phillips et al.  
435 2019), even though size ranges largely overlap. This suggests that small BET spend a higher  
436 proportion of their time associated with FOBs than large individuals. This agrees with  
437 observed size distributions of DFAD catches, where smaller individuals are caught, and with  
438 the negative correlation between BET individual length and percentage of time associated  
439 found by Schaefer & Fuller (2002). However, Schaefer et al. (2009) found lower association  
440 percentages with archival tags on small tunas (10.4 and 15.9 % of the time associated for  
441 51-60 cm FL YFT and 65-99 cm FL BET respectively) than the work of Phillips et al. (2019)  
442 with acoustic tagging. This could suggest a potential bias in the different methodologies that  
443 need to be further investigated. A small percentage of time associated with floating objects  
444 would indicate no or little influence of DFADs, while a high percentage could indicate a  
445 potentially significant influence of DFADs which could result in impacts on large-scale  
446 movements.

447 We are therefore far from understanding the effects of different densities of floating objects  
448 on tuna fine-scale movements nor the link between fine-scale and large-scale movements.  
449 Most electronic tagging efforts have been done on YFT and to a lesser extent BET, but more  
450 behavioural data are clearly needed for all three tropical tuna species. One of the main  
451 difficulty is to disentangle the effects of DFADs from the impacts of other external signals  
452 (e.g. prey density) which can also influence tuna associative behaviour (Lopez et al. 2017,  
453 Nooteboom et al. 2023, Schaefer et al., 2009, Schaefer & Fuller, 2010).

#### 454 *Effects on schooling behaviour*

455 DFADs could also affect schooling behaviour, which can have a wide range of consequences  
456 on the life-history parameters and the movements of tunas. Dagorn & Fréon (1999) and  
457 Fréon & Dagorn (2000) suggested that tuna could associate with floating objects for social  
458 advantages such as facilitating the formation of larger schools. Tuna associative behaviour

459 would have been selected because schooling behaviour provides several evolutionary  
460 advantages. It can be seen as an evolutionary trade-off between (i) increasing protection  
461 against predators, swimming and foraging efficiency, mating, and (ii) increasing detection by  
462 predators and intra- and inter-specific competition (Rubenstein 1978; Ioannou 2017; Maury  
463 2017). Hence, if tuna use FOBs for social behaviour, the number of FOBs could affect the  
464 size of schools and therefore reduce their evolutionary advantages, which could impact both  
465 tuna survival and reproduction, resulting in population-scale impacts. To date no result has  
466 been obtained on tropical tuna from DFADs regarding this question. If floating objects  
467 facilitate the schooling behaviour of tunas, then the deployment of large numbers of DFADs  
468 may have effects on school size, either by facilitating the formation of large (but less) schools  
469 or decreasing school size with DFADs offering too many aggregation sites (Figure 2, Dagorn  
470 et al., 2010). DFADs could also modify the size structure of tuna schools, allowing the  
471 formation of large aggregations composed of several unassociated schools of different size  
472 structures (Wang et al. 2012). Sempo et al. (2013) modelled the impact of the increasing  
473 deployment of DFADs on the distribution of social fish species such as tunas. They  
474 demonstrated that for social species, increasing the number of DFADs does not necessarily  
475 lead to an increase in the total amount of tuna associated with DFADs, a non-intuitive result.  
476 Capello et al. (2022) also showed that the number of DFADs with associated schools and the  
477 size of associated schools were not linearly related to the total number of DFADs and that  
478 this relationship varied according to the considered social scenario.

#### 479 **Do DFADs modify the life-history parameters of tropical tunas?**

480 The increasing number of DFADs at sea also raises questions regarding their effect on the  
481 feeding strategy of tropical tuna, and related energy-dependent traits such as tuna health  
482 (monitored for example by body condition), growth, reproduction and natural mortality.

#### 483 *Effects on feeding*

484 In his review on DFAD impacts on tropical tunas, Taquet (2013) recommended comparative  
485 analyses of stomach contents on tropical tunas. Such analyses have shown that small-sized

486 tunas may not feed while associated with DFADs in the Atlantic (Hallier & Gaertner, 2008;  
487 Ménard et al., 2000), Indian (Grande et al., 2013; Jaquemet et al., 2011; Zudaire et al., 2015,  
488 Malone et al. 2011, Hallier & Gaertner, 2008) and Western and Central Pacific (Machful et  
489 al., 2021) oceans. Small YFT and SKJ captured in DFAD-associated schools had a higher  
490 fraction of empty stomachs, lower stomach fullness or daily food rates (in the EAO; Hallier &  
491 Gaertner 2008, Ménard et al. 2000; and in the IO, Hallier & Gaertner 2008), and lower prey  
492 weight (in the IO; Grande et al. 2013, Zudaire et al. 2015) than those captured in free-  
493 swimming schools. These results support the hypothesis that the quantity of prey present in  
494 DFAD assemblages is not sufficient to sustain the dietary requirements of large aggregations  
495 of small-sized tuna commonly found at DFADs (several tens of tons) (Fréon & Dagorn,  
496 2000). Hence, if tuna were to spend more time associated with FOBs, due to the increase in  
497 the number of FOBs induced by the deployment of DFADs, it could impact their feeding  
498 behaviour, potentially resulting in an increase in their natural mortality. However, evidence is  
499 still too scarce to allow the determination and quantification of this potential increase of  
500 natural mortality. Also, except in Hallier & Gaertner (2008), the influence of the sampling time  
501 of tunas on the stomach content was not taken into account. Purse seine vessels mainly fish  
502 on DFADs at dawn (Forget et al., 2015) and on free-swimming schools during daytime. First,  
503 feeding activities are believed to often take place in the early evening on organisms  
504 performing diel vertical migration between the deep scattering layer and the surface  
505 (Schaefer & Fuller, 2002), resulting in prey being fully digested by the time the fish are  
506 caught and sampled, at dawn. Second, free-swimming schools of tunas are almost  
507 exclusively caught when actively feeding at the sea surface, hence higher levels of stomach  
508 fullness are to be expected. Nevertheless, the association of tunas with DFADs could also  
509 affect the composition and quality of their diet, as shown for YFT in the Western IO (WIO)  
510 and WCPO and for SKJ in the WCPO (Zudaire et al. 2015, Allain et al. 2010). Differences of  
511 diet composition were observed for these species, that may be due to their associative  
512 behaviour despite the above-mentioned sampling bias, with associated tuna in the WCPO  
513 feeding on shallower prey than free-swimming tunas (Allain et al. 2010), which is in

514 agreement with YFT staying closer to the surface when associated (Holland and Brill, 1990,  
515 Schaefer et al. 2009).

516 Independently of the trophic role of DFADs, the deployment and the drift trajectories of  
517 DFADs could create new zones of high floating object densities, which may be unfavourable  
518 for the foraging success of tunas, resulting in an increase of natural mortality (Marsac et al.  
519 2000). In the Western Indian Ocean, Jaquemet et al. (2011) found that in “rich” forage areas,  
520 DFADs have no impact on the feeding pattern of tunas, whereas in “poor” forage areas,  
521 tunas associated with DFADs had lower stomach fullness compared to tunas in free-  
522 swimming schools. The authors suggested that the impact of DFADs on feeding success  
523 could be location-dependent, leading them to emphasize the possible detrimental effect on  
524 the condition of tuna associated with DFADs if associated tunas drift towards areas with poor  
525 forage resources. However, such an effect relies on the assumption that a tuna’s probability  
526 to depart from a DFAD is independent of their local environment which seems in  
527 disagreement with behavioural studies (Fuller et al. 2015, Nootboom et al. 2023).

528 In the Pacific Ocean, Hunsicker et al. (2012) observed that predation on SKJ and YFT by  
529 large pelagic fishes sampled from DFAD sets was greater than for those captured via other  
530 fishing methods (e.g. free-swimming schools). These authors concluded that by aggregating  
531 small-sized SKJ, YFT, and BET, DFADs enhance their vulnerability to predators such as  
532 sharks and billfishes, and thus increase natural mortality of small sized tunas. To our  
533 knowledge, this is the only study assessing the impact of DFADs on tuna vulnerability to  
534 predators, hence additional data from other regions would be needed for further testing these  
535 assumptions.

### 536 *Effects on body condition*

537 Individual condition can be seen as a proxy of individual’s fitness, as it can impact both the  
538 individual survival and reproduction (Lloret et al. 2014). Tuna condition has been investigated  
539 using different methods: biometric condition factors (e.g. plumpness), and biochemical  
540 indices (e.g., fat and water contents, lipid class composition). Gaertner et al. (1999) in a  
541 preliminary investigation did not find evidence of a morphometric difference between free-

542 swimming school or DFAD-caught tunas in the EAO. But Marsac et al. (2000) in the EAO  
543 and Hallier & Gaertner (2008) in the WIO found that individuals associated with DFADs were  
544 in lower condition than those in free-swimming schools, using morphometric indicators  
545 (thorax width or girth, plumpness of fish) as fish health indicators. This result suggests that  
546 DFADs, by reducing individual condition, could increase tuna natural mortality and/or impact  
547 their reproduction (specifically for SKJ who also associate to DFADs when they are mature).  
548 Robert et al. (2014) measured the condition of SKJ using BIA (Bioelectrical Impedance  
549 Analysis), a non-invasive field tool that estimates body water content (inversely correlated  
550 with body fat content), and determines total lipid and main lipid class concentrations. They  
551 confirmed the lower condition of SKJ associated with floating objects compared to those in  
552 free-swimming schools. Because the studied area (Mozambique Channel, WIO) is naturally  
553 rich with NLOGs and had undergone little habitat modifications due to DFADs at the time of  
554 the study (Dagorn et al., 2013a, Dupaix et al. 2021), the authors concluded that before the  
555 use of DFADs, tunas associated with logs could have also been in lower condition than tunas  
556 in free-swimming schools. These results can mean that (1) a lower measured condition could  
557 reflect normal variations and does not necessarily imply detrimental physiological  
558 consequences, or (2) some specific areas where NLOGs have always been in high numbers  
559 could also have negatively impacted the condition of tunas that passed through and stayed in  
560 these areas.

561 As a lower condition measured at DFADs does not necessarily imply longer-term detrimental  
562 consequences for tuna, there is a need to monitor tuna condition and other biological  
563 parameters on a longer term and determine if they are influenced by the density of DFADs in  
564 the area. Dupaix et al. (2023), using length-weight data from 1987 to 2018 in the WIO, found  
565 no decreasing trend of YFT condition over the studied period, during which the number of  
566 DFADs has increased. Hence, this study, using one morphometric indicator as a proxy for  
567 condition (Le Cren's relative condition factor), suggests the absence of a long-term impact of  
568 DFADs on YFT condition, under the conditions encountered in the WIO in the last three  
569 decades. Nevertheless, it should be noted that other factors could also have counteracted  
570 potential negative effects of DFADs on tuna condition.

571 Studies that investigated potential DFAD impacts on tuna condition mainly suggest that the  
572 condition of associated tuna is lower than that of free-swimming tuna. These results are  
573 reinforced by the example of the preparation of katsuobushi (shaved dried SKJ) in Japan.  
574 Indeed the Japanese tuna industry prefers SKJ caught on DFADs as they have less fat than  
575 those from free-swimming schools (Nishida, pers. comm.). However, Sardenne et al. (2016),  
576 when comparing biometric and biochemical indicators found inconsistencies due to a high  
577 variability of biometric indicators with season and ontogeny. They concluded that biometric  
578 indicators measured on whole tuna (e.g. thorax girth, fish plumpness, Le Cren's  $K_n$ ) should  
579 be interpreted with caution as they may not always reflect the energetic condition measured  
580 in the tissues of the fish. Experimental validation of the condition factors used is needed to  
581 determine the potential impacts and the underlying mechanisms of the difference in tuna  
582 condition. For example, condition factors could be calibrated and validated by monitoring  
583 them during fasting experiments on captive tuna, although measuring some of them regularly  
584 in experimental conditions could represent a methodological challenge.

#### 585 *Effects on reproduction and growth*

586 DFADs, by decreasing tropical tuna condition, could also impact reproductive potential,  
587 which could decrease population resilience. In the WIO, Zudaire et al. (2014, 2015) found (i)  
588 a significantly higher proportion of energy-rich fish prey in the diet (stomach contents;  
589 Zudaire et al., 2015), as well as (ii) significantly higher total lipid concentrations and  
590 triacylglycerol to sterol (TAG:ST) ratio, indicators of energetic condition, in the gonads of YFT  
591 females caught in free-swimming schools compared to females associated with DFADs  
592 (Zudaire et al., 2014). This can be interpreted as simply reflecting differences in prey  
593 availability and feeding activity and thus differential lipid incorporation to tissues between  
594 DFAD-associated and non-associated tunas. It could also highlight higher energetic  
595 investment to reproduction in free-swimming YFT due to a higher condition (i.e., better  
596 health), keeping in mind the potential bias provoked by an uneven size distribution between  
597 school types in these studies. However, the study failed to demonstrate a direct effect on the

598 fecundity, most likely due to the low number of actively spawning females analysed and the  
599 high inter-individual fecundity variability observed in YFT (Pecoraro et al., 2017).

600 Similarly, Ashida et al. (2017) investigated the difference in reproductive traits of female SKJ,  
601 of similar size distribution, between school types in the WCPO, highlighting a significant  
602 higher proportion of mature females in free swimming schools, characterised by higher  
603 relative condition factor, than associated with DFADs. However, as for YFT in the IO (Zudaire  
604 et al. 2014), no significant effect of the school type was observed on the WCPO SKJ  
605 fecundity, which corroborates previous results observed for WIO SKJ (Grande, 2013; Grande  
606 et al. 2014). Also, an investigation of the reproductive dynamics of SKJ in the EPO based on  
607 the histological evaluations of ovaries from 3732 females indicated spawning was observed  
608 for fish captured in both unassociated and floating object sets (Schaefer and Fuller 2019).  
609 The lack of relationship between condition and fecundity of SKJ could be related to their  
610 energy allocation and reproductive strategies. SKJ tuna females fuel their gametes with  
611 energy gained concomitantly during reproduction (i.e., income breeding strategy, Grande et  
612 al. 2016). However, YFT females can store additional energy reserves prior to spawning,  
613 which define them as income-capital breeder (Zudaire et al., 2014) unlike SKJ. Therefore, as  
614 SKJ females exhibit better condition when free swimming, it can be assumed that their  
615 reproductive efficiency is lower when associated with DFADs, but the same conclusion  
616 cannot be made for YFT.

617 Using tagging data collected in the EAO, Hallier & Gaertner (2008) estimated and compared  
618 the growth rates of SKJ and YFT associated with DFADs versus free-swimming schools.  
619 Released and recaptured SKJ associated with DFADs had a significantly lower growth rate  
620 than those in free-swimming schools, but the difference was not significant for YFT (though it  
621 was lower, as for SKJ). However, the history experienced by individual fish between release  
622 and recapture was unknown. The “experimental” design could not be controlled as the time  
623 one specimen spent associated with DFADs and in free-swimming schools is not available.



624 **What are the scientific challenges to fill the knowledge gaps?**

625 DFADs have been representing one of the key management priorities and challenges of  
626 tRFMOs over the last decade. Since fishers started using them, DFADs numbers  
627 continuously increased until first management measures limiting the number of operational  
628 buoys were adopted in the mid-2010s (Song & Shen 2022). The massive use of DFADs in all  
629 oceans has been generating major concerns on the sustainability of this fishing mode.  
630 DFADs increase the catchability of tropical tunas leading to large catches of small BET and  
631 YFT (Dagorn et al., 2013b; Fonteneau et al., 2013), generate more bycatch, including  
632 vulnerable species such as some shark species, silky (*Carcharhinus falciformis*) and oceanic  
633 whitetip (*Carcharhinus longimanus*) sharks (Dagorn et al., 2013b; Fonteneau et al., 2013;  
634 Leroy et al., 2013), and can strand on coastal areas causing damage to marine habitats  
635 (Imzilen et al., 2021; Maufroy et al., 2015, Escalle et al. 2019). Although there is increasing  
636 knowledge and literature on DFADs, the issue of their indirect impacts (not related to fishing  
637 mortality) on tropical tuna remains an open scientific question. Several pieces of evidence  
638 demonstrate that DFADs increase tuna catchability, increasing their fishing mortality (Davies  
639 et al. 2014; Wain et al. 2021). However, if indirect impacts were to be demonstrated at the  
640 population level, DFAD impacts could be even greater, also increasing tuna natural mortality  
641 and impacting reproductive potential. Furthermore, direct and indirect impacts could have  
642 cumulative effects on tuna populations. All knowledge collected and reviewed on the  
643 behaviour and life-history parameters of tunas at DFADs clearly reveals a lack of converging  
644 scientific results on the long term consequences on tuna (at the individual and/or population  
645 levels) of increased numbers of floating objects. Therefore, if DFADs seem to affect the  
646 short-term condition of tropical tunas, we are not currently able to conclude whether DFADs  
647 affect the movements and/or other life-history parameters of tunas in a way that could  
648 significantly affect the fitness of individuals and the demography of their populations. As  
649 such, there is a need to improve our observation and understanding of this associative  
650 phenomenon to determine with certainty the indirect impacts of DFADs on the life-history  
651 parameters and behaviour of tropical tuna, quantify the magnitude of these impacts and  
652 provide evidence-based advice.

653 A major gap in tuna and DFAD science is the lack of time series of key parameters such as  
654 the numbers of DFADs and natural floating objects, residence and absence times at DFADs  
655 as well as large movements between oceanic regions, school sizes, condition and  
656 reproduction indices. The first research priority in this context is to initiate or continue time  
657 series of such indicators (Capello et al. 2023). Setting long-term monitoring programs in  
658 every ocean appears to be a priority, as effects of DFADs could vary depending on the  
659 species, the characteristics of each ecosystem and on the density of floating objects.  
660 Moreover, it would facilitate comparative analyses between oceans to better understand the  
661 drivers of tuna associative behaviour. The collection of some parameters will require  
662 dedicated scientific surveys (e.g. electronic tagging, biological sampling) while others (e.g.  
663 numbers of DFADs and natural objects, biological condition factors) have started to be  
664 routinely collected by tRFMOs through FAD-specific data requirements included in  
665 conservation and management measures (Grande et al. 2018, Báez et al. 2022, Song &  
666 Shen 2022) as well as government and industry initiatives (e.g., routine fishery monitoring  
667 and at-sea observer programs).

668 Another research priority is to develop experimental studies to identify the biological and  
669 behavioural processes involved in tuna associative behaviour. The only scientific consensus  
670 is the fact that in a given area, conditions of tunas associated with floating objects often  
671 seem to be lower than those of fish in free-swimming schools. However, the different  
672 indicators used to assess tuna condition are not always well correlated (Sardenne et al.  
673 2016), and experimental studies are needed to validate them against proper benchmarks,  
674 allowing to determine how representative they are of individuals' health. Then, understanding  
675 how fast these indicators change with the fish's associative behaviour appears essential.  
676 This could also be achieved through studies on captive tropical tunas (e.g., Estess et al.  
677 2017), but non-lethal observations should be promoted (e.g. BIA) in order to track changes  
678 throughout the fish lifespan. No evidence exists suggesting whether the lower condition at  
679 DFADs is the consequence or the cause of their association with DFADs. Often the  
680 robustness of the findings of investigation on the life-history parameters of tunas is hampered  
681 by the lack of knowledge of the time spent associated with a DFAD or in an array of DFADs

682 by each specimen analysed. The history of each individual tuna is a hidden variable that  
683 must be taken into account in statistical analyses, which is a challenge. Studies combining  
684 behavioural observations (tagging) and condition of the individuals (e.g. BIA or biochemical  
685 analyses of biopsies made at the time of tagging) should then be encouraged. Ideally, tags  
686 equipped with physiological sensors would clearly help understanding the interplay between  
687 associative behaviour and tuna physiology. Such tags, however, are only starting to be  
688 developed.

689 Studies on AFADs could provide insights to the questions addressed in this manuscript: as  
690 argued by Dagorn et al. (2010), AFADs also alter the natural environment (by adding floating  
691 objects to the ocean). However, it remains questionable if they are comparable due to the  
692 fact that AFADs are generally located nearshore, with corresponding particular  
693 oceanographic conditions, and they do not move with water masses. Papua New Guinea, the  
694 Philippines and Indonesia are examples of areas with very high numbers of AFADs (Proctor  
695 et al. 2019) and as such, these dense arrays of AFADs could generate the same concerns  
696 on tuna life-history parameters and behaviour that those described for DFADs.  
697 Understanding the behaviour of tunas around AFADs can also improve our general  
698 understanding of tunas around all types of floating objects and help design new, well focused  
699 studies for DFADs. For practical reasons, more studies have been performed on the  
700 behaviour of tuna at AFADs than at DFADs (e.g. Dagorn et al., 2007; Govinden et al., 2013;  
701 Holland et al., 1990; Ohta & Kakuma, 2005; Rodriguez-Tress et al., 2017). They provided  
702 estimates of residence times between two AFAD associations and therefore of the  
703 percentage of time spent associated to AFADs (e.g. Pérez et al., 2020; Robert et al., 2013b;  
704 Rodriguez-Tress et al., 2017), which still needs to be further explored at DFADs. For  
705 example, Pérez et al. (2020) used acoustic tagging data on AFAD arrays to demonstrate that  
706 when inter-AFAD distance decreases, tuna visit more AFADs, spend less time travelling  
707 between AFADs and more time associated with them. Concerning DFADs, as actual  
708 densities of drifting floating objects are difficult to obtain, studies using a modelling approach  
709 based on experimental data should be promoted (Pérez et al. 2022, Capello et al. 2023).  
710 These studies should investigate the consequences of changes in floating object density on

711 tuna school sizes and associative behaviour. These modelling studies could be  
712 complemented and/or calibrated by studies which use data from echosounder buoys  
713 deployed by fishers on floating objects. Recent methodological advances allowed the  
714 prediction of tuna presence or absence under FOBs (Baidai et al., 2020; Orue et al., 2020).  
715 Using an extensive dataset from echosounder buoys in the WCPO (more than 3.8 million  
716 transmissions), Escalle et al. (2021c) determined different profiles of acoustic signals related  
717 to different types of aggregations. Other studies also show that multi-frequency echosounder  
718 buoys could allow the discrimination of tropical tuna species under DFADs (Moreno et al.  
719 2019, Sobradillo et al. 2023). These new methodological developments, in combination with  
720 tagging data, both conventional and electronic, and modelling approaches offer promising  
721 perspectives for the study of tuna aggregation behaviour under FOBs and the potential  
722 impact of DFAD density on tuna schooling behaviour.

723 Tuna RFMOs set limits on the number of operational buoys (IATTC: up to 340 depending on  
724 the vessel size, Res C-21-04; ICCAT: 300 in Rec 22-01; IOTC: 300 in Res 19/02; WCPFC:  
725 350 in CMM 2021-01). These limits are essentially set to control the fishing effort and the  
726 catches of tunas and non-target species, hence to control fishing mortality. How such limits  
727 also act on the number of deployed DFADs and the potential impacts of DFADs on tuna's  
728 natural mortality, is unknown. In theory, all purse seine vessels could use at least the same  
729 amount of DFADs than the maximum number of operational buoys authorized in each of the  
730 regions. Multiplying this maximum number of operational buoys authorized per vessel by the  
731 number of large-scale purse seine vessels in each ocean provides a global authorized limit of  
732 about 238,000 operational buoys (details of the calculation in Supplementary Materials 1).  
733 This number is about twice higher than the estimate of the global number of DFADs  
734 deployments made by Gershman et al. (2015), based on data from 2013. Hence, it would  
735 mean that the global purse seine fishery could have increased the number of DFADs in the  
736 ocean while still respecting the current limits on the number of active buoys. Most tRFMOs  
737 now require that DFAD identification, characteristics, deployment date and deployment  
738 location are reported (e.g. ICCAT Rec 22-01; IOTC Res. 19/02; IATTC C-21-04). Some  
739 studies evidenced different regional trends of DFAD deployments (IOTC, 2022, Escalle et al.

740 2020, Lopez et al. 2021, Floch et al., 2019; Maufroy et al., 2017), but no study assessed this  
741 trend on a global scale after 2013 (Gershman et al., 2015). Tuna RFMOs should continue to  
742 collect and make fine-scale DFAD data available to scientists to allow regular estimations of  
743 the extent of the habitat modifications generated by DFADs, which should be addressed at a  
744 global scale.

## 745 **Conclusion**

746 This study reviews the current state of knowledge on the indirect impacts of DFADs on  
747 tropical tuna, i.e. how DFADs could also impact natural mortality and reproduction  
748 additionally to their impact on fishing mortality. To summarize the questions formulated:

749 (1) although the deployment of DFADs has undoubtedly modified the habitat of tropical  
750 tunas, the extent of this modification still needs to be better characterized in some regions.  
751 This characterization can be achieved through the continued monitoring of indicators (e.g.  
752 spatialized DFAD and NLOG densities, DFAD/NLOG ratio) collected by tRFMOs.

753 (2) studies assessing the impacts of DFADs on tuna large-scale movements show  
754 contradictory results. Strong ocean and species-specific variability is observed for the  
755 proportion of time spent associated with FOBs. However, the effect of the methodology used  
756 (archival tagging vs acoustic tagging) should be investigated. To date, besides theoretical  
757 studies, no evidence has been shown on the impact of DFADs on associative and schooling  
758 behaviour.

759 (3) DFADs probably impact tuna short-term condition, but it does not necessarily imply a  
760 longer-term detrimental effect and should be confirmed with long-term time series of  
761 validated condition indicators. The results on the impacts of DFADs on other life-history  
762 parameters are inconclusive.

763 (4) The main conclusion of this work is the lack of clear converging scientific results on the  
764 indirect impacts of DFADs on the behaviour and life-history parameters of tropical tuna. It  
765 should therefore be underlined that scientific efforts should not only focus on the direct  
766 effects of DFADs on catches (target and non-target species) but should also address other

767 possible impacts, such as density dependent effects on the behaviour and life-history  
768 parameters of tunas. This current lack of converging results justifies a major and urgent  
769 scientific effort, in terms of data collection, experimental research and modelling to tackle  
770 definitively whether the increased deployment of DFADs could lead to indirect impacts on  
771 tropical tuna populations.

## 772 **Acknowledgements**

773 The initial impetus for this work was a workshop funded by the International Seafood  
774 Sustainability Foundation (ISSF, 2014). The research was conducted independently by the  
775 authors and its results, professional opinions and conclusions are solely the work of the  
776 authors. There are no contractual obligations between ISSF and the authors that might  
777 influence the results, professional opinions and conclusions. For the purpose of Open  
778 Access, a CC-BY public copyright licence has been applied by the authors to the present  
779 document and will be applied to all subsequent versions up to the Author Accepted  
780 Manuscript arising from this submission.

## 781 **Data availability statement**

782 Data used in the supplementary material were obtained from Justel-Rubio et al. (2023) and  
783 the following website: <https://www.iattc.org/en-US/Management/Vessel-register> (accessed  
784 2023/03/14)

785 **References**

- 786 Abascal, F. J., Peatman, T., Leroy, B., Nicol, S., Schaefer, K., Fuller, D. W., & Hampton, J.  
787 (2018). Spatiotemporal variability in bigeye vertical distribution in the Pacific Ocean.  
788 *Fisheries Research*, 204, 371–379. <https://doi.org/10.1016/j.fishres.2018.03.013>
- 789 Allain, V. (2010). *Trophic structure of the pelagic ecosystems of the western and central*  
790 *Pacific Ocean* (6th Regular Session of the Scientific Commity EB-IP-10). Western and  
791 Central Pacific Fisheries Commission. <https://meetings.wcpfc.int/index.php/node/7069>
- 792 Amandè, M. J., Chassot, E., Chavance, P., Murua, H., de Molina, A. D., & Bez, N. (2012).  
793 Precision in bycatch estimates: The case of tuna purse-seine fisheries in the Indian Ocean.  
794 *ICES Journal of Marine Science*, 69(8), 1501–1510. <https://doi.org/10.1093/icesjms/fss106>
- 795 Ariz, J., Delgado, A., Fonteneau, A., Gonzalez Costas, F., & Pallares, P. (1999). Logs and  
796 tunas in the Eastern Tropical Atlantic. A review of present knowledge and uncertainties. In  
797 M. D. Scott, W. H. Bayliff, C. E. Lennert-Cody, & K. M. Schaefer (Eds.), *Proceedings of the*  
798 *International Workshop on Fishing for Tunas Associated with Floating Objects* (Vol. 11, pp.  
799 21–65). Inter-American Tropical Tuna Commission.
- 800 Arrizabalaga, H., Ariz, J., Mina, X., De Molina, A. D., Artetxe, I., Pallares, P., & Iriondo, A.  
801 (2001). *Analysis of the activities of supply vessels in the Indian Ocean from observers data*  
802 (Working Party on Tropical Tunas (WPTT)). Indian Ocean Tuna Commission.  
803 <https://iotc.org/documents/analysis-activities-supply-vessels-indian-ocean-observers-data>
- 804 Artetxe-Arrate, I., Fraile, I., Marsac, F., Farley, J. H., Rodriguez-Ezpeleta, N., Davies, C. R.,  
805 Clear, N. P., Grewe, P., & Murua, H. (2021). A review of the fisheries, life history and stock  
806 structure of tropical tuna (skipjack *Katsuwonus pelamis*, yellowfin *Thunnus albacares* and  
807 bigeye *Thunnus obesus*) in the Indian Ocean. *Advances in Marine Biology*, 88, 39–89.  
808 <https://doi.org/10.1016/bs.amb.2020.09.002>
- 809 Ashida, H., Tanabe, T., & Suzuki, N. (2017). Difference on reproductive trait of skipjack tuna  
810 *Katsuwonus pelamis* female between schools (free vs FAD school) in the tropical western and  
811 central Pacific Ocean. *Environmental Biology of Fishes*, 100(8), 935–945.  
812 <https://doi.org/10.1007/s10641-017-0621-2>
- 813 Báez, J. C., Déniz, S., Ramos, M. L., Grande, M., Ruiz, J., Murua, H., Santiago, J., Justel-  
814 Rubio, A., Herrera, M., Moniz, I., Lopez, J., Pascual-Alayón, P. J., Muniategi, A., Alzorritz,  
815 N., González-Carballo, M., Rojo, V., & Abascal, F. (2022). Data Provision for Science-Based  
816 FAD Fishery Management: Spanish FAD Management Plan as a Case Study. *Sustainability*,  
817 14(6), Article 6. <https://doi.org/10.3390/su14063278>
- 818 Baidai, Y., Dagorn, L., Amande, M. J., Gaertner, D., & Capello, M. (2020). Machine learning  
819 for characterizing tropical tuna aggregations under Drifting Fish Aggregating Devices  
820 (DFADs) from commercial echosounder buoys data. *Fisheries Research*, 229, 105613.  
821 <https://doi.org/10.1016/j.fishres.2020.105613>
- 822 Baske, A., Gibbon, J., Benn, J., & Nickson, A. (2012). Estimating the use of drifting Fish  
823 Aggregation Devices (FADs) around the globe. *PEW Environment Group - Discussion Paper*,  
824 1–8.
- 825 Battin, J. (2004). When Good Animals Love Bad Habitats: Ecological Traps and the  
826 Conservation of Animal Populations. *Conservation Biology*, 18(6), 1482–1491.  
827 <https://doi.org/10.1111/j.1523-1739.2004.00417.x>
- 828 Brehmer, P., Sancho, G., Trygonis, V., Itano, D., Dalen, J., Fuchs, A., Faraj, A., & Taquet, M.  
829 (2019). Towards an autonomous pelagic observatory: Experiences from monitoring fish  
830 communities around drifting FADs. *Thalassas: An International Journal of Marine Sciences*,  
831 35, 177–189.

832 Bromhead, D., Foster, J., Attard, R., Findlay, J., & Kalish, J. (2003). *A review of the impact of*  
833 *fish aggregating devices (fads) on tuna fisheries: Final report to the fisheries resources*  
834 *research fund*. Bureau of Rural Sciences.

835 Caddy, J. F., & Majkowski, J. (1996). Tuna and trees: A reflection on a long-term perspective  
836 for tuna fishing around floating logs. *Fisheries Research*, 25(3), 369–376.  
837 [https://doi.org/10.1016/0165-7836\(95\)00449-1](https://doi.org/10.1016/0165-7836(95)00449-1)

838 Capello, M., Merino, G., Tolotti, M., Murua, H., & Dagorn, L. (2023). Developing a science-  
839 based framework for the management of drifting Fish Aggregating Devices. *Marine Policy*,  
840 153, 105657. <https://doi.org/10.1016/j.marpol.2023.105657>

841 Capello, M., Rault, J., Deneubourg, J.-L., & Dagorn, L. (2022). Schooling in habitats with  
842 aggregative sites: The case of tropical tuna and floating objects. *Journal of Theoretical*  
843 *Biology*, 547, 111163. <https://doi.org/10.1016/j.jtbi.2022.111163>

844 Castro, J. J., Santiago, J. A., & Santana-Ortega, A. T. (2002). A general theory on fish  
845 aggregation to floating objects: An alternative to the meeting point hypothesis. *Reviews in*  
846 *Fish Biology and Fisheries*, 11, 255–277. <https://doi.org/10.1023/A:1020302414472>

847 Cayré, P., Diouf, T., Fonteneau, A., & Santa-Rita Vieira, M. H. (1986). Analyse de Données  
848 de Marquages et Recaptures de Listao (*Katsuwonus pelamis*) réalisées par le Sénégal et la  
849 République du Cap-Vert (pp. 309–316). International Commission for the Conservation of  
850 Atlantic Tunas. [https://www.iccat.int/Documents/CVSP/SJ001\\_1986/SJYrProg01.html](https://www.iccat.int/Documents/CVSP/SJ001_1986/SJYrProg01.html)

851 Chassot, E., Goujon, M., Maufroy, A., Cauquil, P., Fonteneau, A., & Gaertner, D. (2014). The  
852 use of artificial fish aggregating devices by the French tropical tuna purse seine fleet:  
853 Historical perspective and current practice in the Indian Ocean. *16ème Groupe de Travail Sur*  
854 *Les Thons Tropicaux*. CTOI, Victoria, p. 17p.

855 Dagorn, L., Bez, N., Fauvel, T., & Walker, E. (2013a). How much do fish aggregating  
856 devices (FADs) modify the floating object environment in the ocean? *Fisheries*  
857 *Oceanography*, 22(3), 147–153. <https://doi.org/10.1111/fog.12014>

858 Dagorn, L., Filmlalter, J. D., Forget, F., Amandè, M. J., Hall, M. A., Williams, P., Murua, H.,  
859 Ariz, J., Chavance, P., & Bez, N. (2012). Targeting bigger schools can reduce ecosystem  
860 impacts of fisheries. *Canadian Journal of Fisheries and Aquatic Sciences*, 69(9), 1463–1467.  
861 <https://doi.org/10.1139/f2012-089>

862 Dagorn, L., & Fréon, P. (1999). Tropical tuna associated with floating objects: A simulation  
863 study of the meeting point hypothesis. *Canadian Journal of Fisheries and Aquatic Sciences*,  
864 56(6), 984–993. <https://doi.org/10.1139/f98-209>

865 Dagorn, L., Holland, K. N., & Filmlalter, J. (2010). Are drifting FADs essential for testing the  
866 ecological trap hypothesis? *Fisheries Research*, 106(1), 60–63.  
867 <https://doi.org/10.1016/j.fishres.2010.07.002>

868 Dagorn, L., Holland, K. N., & Itano, D. G. (2007). Behavior of yellowfin (*Thunnus*  
869 *albacares*) and bigeye (*T. obesus*) tuna in a network of fish aggregating devices (FADs).  
870 *Marine Biology*, 151(2), 595–606. <https://doi.org/10.1007/s00227-006-0511-1>

871 Dagorn, L., Holland, K. N., Restrepo, V., & Moreno, G. (2013b). Is it good or bad to fish with  
872 FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems?  
873 *Fish and Fisheries*, 14(3), 391–415. <https://doi.org/10.1111/j.1467-2979.2012.00478.x>

874 Davies, T. K., Mees, C. C., & Milner-Gulland, E. J. (2014). The past, present and future use  
875 of drifting fish aggregating devices (FADs) in the Indian Ocean. *Marine Policy*, 45, 163–170.  
876 <https://doi.org/10.1016/j.marpol.2013.12.014>

877 Delgado de Molina, A., Ariz, J., Murua, H., Santana, J. C., Ramos, L., & Soto, M. (2014).  
878 *Spanish Fish Aggregating Device Management Plan. Preliminary data in the Indian Ocean*



879 (IOTC-2014-WPTT16-19). Indian Ocean Tuna Commission.  
880 [https://iotc.org/sites/default/files/documents/2014/11/IOTC-2014-WPTT16-19\\_Rev\\_1 -](https://iotc.org/sites/default/files/documents/2014/11/IOTC-2014-WPTT16-19_Rev_1_-_Spanish_FAD_Mgt_plan.pdf)  
881 [\\_Spanish FAD Mgt plan.pdf](https://iotc.org/sites/default/files/documents/2014/11/IOTC-2014-WPTT16-19_Rev_1_-_Spanish_FAD_Mgt_plan.pdf)

882 Dempster, T., & Taquet, M. (2004). Fish aggregation device (FAD) research: Gaps in current  
883 knowledge and future directions for ecological studies. *Reviews in Fish Biology and*  
884 *Fisheries*, 14(1), 21–42. <https://doi.org/10.1007/s11160-004-3151-x>

885 Dupaix, A., Capello, M., Lett, C., Andrello, M., Barrier, N., Viennois, G., & Dagorn, L.  
886 (2021). Surface habitat modification through industrial tuna fishery practices. *ICES Journal of*  
887 *Marine Science*, 78(9), 3075–3088. <https://doi.org/10.1093/icesjms/fsab175>

888 Dupaix, A., Dagorn, L., Duparc, A., Guillou, A., Deneubourg, J.-L., & Capello, M. (2023).  
889 No evidence from long- term analysis of yellowfin tuna condition that Drifting Fish  
890 Aggregating Devices act as ecological traps. *Marine Ecology Progress Series*, 711, 121–127.  
891 <https://doi.org/10.3354/meps14313>

892 Escalle, L., Gaertner, D., Chavance, P., Murua, H., Simier, M., Pascual-Alayón, P. J.,  
893 Ménard, F., Ruiz, J., Abascal, F., & Mérigot, B. (2018). Catch and bycatch captured by  
894 tropical tuna purse-seine fishery in whale and whale shark associated sets: Comparison with  
895 free school and FAD sets. *Biodiversity and Conservation*, 28(2), 467–499.  
896 <https://doi.org/10.1007/s10531-018-1672-1>

897 Escalle, L., Hare, S. R., Vidal, T., Brownjohn, M., Hamer, P., & Pilling, G. (2021a).  
898 Quantifying drifting Fish Aggregating Device use by the world’s largest tuna fishery. *ICES*  
899 *Journal of Marine Science*, fsab116. <https://doi.org/10.1093/icesjms/fsab116>

900 Escalle, L., Muller, B., Vidal, T., Hare, S., Hamer, P., & PNA Office. (2021b). *Report on*  
901 *analyses of the 2016/2021 PNA FAD tracking programme* (17th Regular Session of the  
902 Scientific Commity No. SC17-MI-IP-04). Western and Central Pacific Fisheries Commission.  
903 <https://meetings.wcpfc.int/node/12589>

904 Escalle, L., Phillips, J. S., Brownjohn, M., Brouwer, S., Gupta, A. S., Sebille, E. V., Hampton,  
905 J., & Pilling, G. (2019). Environmental versus operational drivers of drifting FAD beaching in  
906 the Western and Central Pacific Ocean. *Scientific Reports*, 9(1), 1–12.  
907 <https://doi.org/10.1038/s41598-019-50364-0>

908 Escalle, L., Vidal, T., Hare, S., Hamer, P., Pilling, G., & Office, P. (2020). *Estimates of the*  
909 *number of FAD deployments and active FADs per vessel in the WCPO* (16th Regular Session  
910 of the Scientific Commity No. SC16-MI-IP-13). Western and Central Pacific Fisheries  
911 Commission. <https://meetings.wcpfc.int/node/11729>

912 Escalle, L., Vidal, T., Heuvel, B., Clarke, R., Hare, S., Hamer, P., & Pilling, G. (2021c).  
913 *Project 88 final report: Acoustic FAD analyses* (17th Regular Session of the Scientific  
914 Commity No. SC17-MI-IP-05). Western and Central Pacific Fisheries Commission.  
915 <https://meetings.wcpfc.int/node/12590>

916 Estess, E. E., Klinger, D. H., Coffey, D. M., Gleiss, A. C., Rowbotham, I., Seitz, A. C.,  
917 Rodriguez, L., Norton, A., Block, B., & Farwell, C. (2017). Bioenergetics of captive  
918 yellowfin tuna (*Thunnus albacares*). *Aquaculture*, 468, 71–79.  
919 <https://doi.org/10.1016/j.aquaculture.2016.09.053>

920 Evans, K., Young, J. W., Nicol, S., Kolody, D., Allain, V., Bell, J., Brown, J. N., Ganachaud,  
921 A., Hobday, A. J., Hunt, B., Innes, J., Gupta, A. S., van Sebille, E., Kloser, R., Patterson, T.,  
922 & Singh, A. (2015). Optimising fisheries management in relation to tuna catches in the  
923 western central Pacific Ocean: A review of research priorities and opportunities. *Marine*  
924 *Policy*, 59, 94–104. <https://doi.org/10.1016/j.marpol.2015.05.003>

925 Filmalter, J. D., Capello, M., Deneubourg, J.-L., Cowley, P. D., & Dagorn, L. (2013).  
926 Looking behind the curtain: Quantifying massive shark mortality in fish aggregating devices.  
927 *Frontiers in Ecology and the Environment*, 11(6), 291–296. <https://doi.org/10.1890/130045>

928 Filous, A., Friedlander, A. M., Griffin, L., Lennox, R. J., Danylchuk, A. J., Mereb, G., &  
929 Golbuu, Y. (2020). Movements of juvenile yellowfin tuna (*Thunnus albacares*) within the  
930 coastal FAD network adjacent to the Palau National Marine Sanctuary: Implications for local  
931 fisheries development. *Fisheries Research*, 230, 105688.  
932 <https://doi.org/10.1016/j.fishres.2020.105688>

933 Floch, L., Depetris, M., Dewals, P., & Duparc, A. (2019). Statistics of the French Purse Seine  
934 Fishing Fleet Targeting Tropical Tunas in the Indian Ocean (1981-2018). *Report of the 21st*  
935 *Session of the IOTC Working Party on Tropical Tunas*, 1–27.  
936 <https://www.iotc.org/documents/WPTT/21/11>

937 Fonteneau, A., Chassot, E., & Bodin, N. (2013). Global spatio-temporal patterns in tropical  
938 tuna purse seine fisheries on drifting fish aggregating devices (DFADs): Taking a historical  
939 perspective to inform current challenges. *Aquatic Living Resources*, 26(1), 37–48.  
940 <https://doi.org/10.1051/alr/2013046>

941 Fonteneau, A., Chassot, E., & Gaertner, D. (2015). Managing tropical tuna purse seine  
942 fisheries through limiting the number of drifting fish aggregating devices: Food for thought.  
943 *Collect. Vol. Sci. Pap. ICCAT*, 71(1), 460–475.  
944 [https://www.iccat.int/Documents/CVSP/CV071\\_2015/n\\_1/CV071010460.pdf](https://www.iccat.int/Documents/CVSP/CV071_2015/n_1/CV071010460.pdf)

945 Fonteneau, A., Pallarés, P., & Pianet, R. (2000). *A worldwide review of purse seine fisheries*  
946 *on FADs*. 28, 15–35.

947 Forget, F. G., Capello, M., Filmalter, J. D., Govinden, R., Soria, M., Cowley, P. D., &  
948 Dagorn, L. (2015). Behaviour and vulnerability of target and non-target species at drifting fish  
949 aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic  
950 telemetry. *Canadian Journal of Fisheries and Aquatic Sciences*, 72(9), 1398–1405.  
951 <https://doi.org/10.1139/cjfas-2014-0458>

952 Fréon, P., & Dagorn, L. (2000). Review of fish associative behaviour: Toward a  
953 generalisation of the meeting point hypothesis. *Reviews in Fish Biology and Fisheries*, 10,  
954 183–207. <https://doi.org/10.1023/A:1016666108540>

955 Fuller, D. W., Schaefer, K. M., Hampton, J., Caillot, S., Leroy, B. M., & Itano, D. G. (2015).  
956 Vertical movements, behavior, and habitat of bigeye tuna (*Thunnus obesus*) in the equatorial  
957 central Pacific Ocean. *Fisheries Research*, 172, 57–70.  
958 <https://doi.org/10.1016/j.fishres.2015.06.024>

959 Gaertner, D., Ariz, J., Bez, N., Clermidy, S., Moreno, G., Murua, H., & Soto, M. (2018).  
960 Results achieved within the framework of the EU research project: Catch, effort, and  
961 ECOsystem impacts of FAD-fishing (CECOFAD). *Collect. Vol. Sci. Pap. ICCAT*, 74(5),  
962 2243–2267.

963 Gaertner, D., Pagavino, M., & Marcano, J. (1999). Influence of fishers' behaviour on the  
964 catchability of surface tuna schools in the Venezuelan purse-seiner fishery in the Caribbean  
965 Sea. *Canadian Journal of Fisheries and Aquatic Sciences*, 56(3), 394–406.  
966 <https://doi.org/10.1139/f98-191>

967 Gaertner, J. C., Taquet, M., Dagorn, L., Mérigot, B., Aumeeruddy, R., Sancho, G., & Itano,  
968 D. (2008). Visual censuses around drifting fish aggregating devices (FADs): A new approach  
969 for assessing the diversity of fish in open-ocean waters. *Marine Ecology Progress Series*, 366,  
970 175–186. <https://doi.org/10.3354/meps07554>

- 971 Garcia, A., & Herrera, M. (2018). Assessing the contribution of purse seine fisheries to  
972 overall levels of bycatch in the Indian Ocean. *IOTC-2018-WPDCS14-26*.  
973 <https://www.iotc.org/documents/WPDCS/14/26-PSBycatch>
- 974 Gershman, D., Nickson, A., & O’Toole, M. (2015). *Estimating the Use of FADs Around the*  
975 *World*. PEW Charitable Trusts. <http://pew.org/1XUPV4w>
- 976 Gilroy, J., & Sutherland, W. (2007). Beyond ecological traps: Perceptual errors and  
977 undervalued resources. *Trends in Ecology & Evolution*, 22(7), 351–356.  
978 <https://doi.org/10.1016/j.tree.2007.03.014>
- 979 Govinden, R., Capello, M., Forget, F., Filmalter, J. D., & Dagorn, L. (2021). Behavior of  
980 skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*T. obsesus*) tunas  
981 associated with drifting fish aggregating devices (dFADs) in the Indian Ocean, assessed  
982 through acoustic telemetry. *Fisheries Oceanography*, 30(5), 542–555.  
983 <https://doi.org/10.1111/fog.12536>
- 984 Govinden, R., Dagorn, L., Filmalter, J., & Soria, M. (2010). Behaviour of Tuna associated  
985 with drifting fish aggregating devices (FADs) in the Mozambique Channel. *IOTC*  
986 *Proceedings. IOTC, Victoria*, 22.
- 987 Govinden, R., Jauhary, R., Filmalter, J., Forget, F., Soria, M., Adam, S., & Dagorn, L. (2013).  
988 Movement behaviour of skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*)  
989 tuna at anchored fish aggregating devices (FADs) in the Maldives, investigated by acoustic  
990 telemetry. *Aquatic Living Resources*, 26(1), Article 1. <https://doi.org/10.1051/alr/2012022>
- 991 Grande, M. (2013). *The reproductive biology, condition and feeding ecology of the skipjack,*  
992 *Katsuwonus pelamis, in the Western Indian Ocean*. <http://www.fao.org/3/bg397e/bg397e.pdf>
- 993 Grande, M., Murua, H., Zudaire, I., Arsenault-Pernet, E. J., Pernet, F., & Bodin, N. (2016).  
994 Energy allocation strategy of skipjack tuna *Katsuwonus pelamis* during their reproductive  
995 cycle. *Journal of Fish Biology*, 89(5), 2434–2448. <https://doi.org/10.1111/jfb.13125>
- 996 Grande, M., Murua, H., Zudaire, I., Goñi, N., & Bodin, N. (2014). Reproductive timing and  
997 reproductive capacity of the Skipjack Tuna (*Katsuwonus pelamis*) in the western Indian  
998 Ocean. *Fisheries Research*, 156, 14–22. <https://doi.org/10.1016/j.fishres.2014.04.011>
- 999 Grande, M., Ruiz, J., Báez, J. C., Ramos, M. L., Zudaire, I., Santiago, J., Pascual, P., Abascal,  
1000 F., Gaertner, D., Cauquil, P., Floch, L., Maufroy, A., Muniategi, A., Herrera, M., & Murua,  
1001 H. (2018). *Best standards for data collection and reporting requirements on FOBs: Towards*  
1002 *a science-based FOB fishery management [IOTC-2018-WPDCS14-39]*. Indian Ocean Tuna  
1003 Commission.
- 1004 Greenblatt, P., R. (1979). Associations of tuna with flotsam in the Eastern Tropical Pacific.  
1005 *Fishery Bulletin*, 77(1), 147–155.
- 1006 Hall, M. (1992). The association of tunas with floating objects and dolphins in the Eastern  
1007 Pacific Ocean. 1992. Part VII. Some hypotheses on the mechanisms governing the association  
1008 of tunas with floating objects and dolphins. In *International Workshop on Fishing for Tunas*  
1009 *Associated with Floating Objects* (p. 7). Inter-American Tropical Tuna Commission.
- 1010 Hallier, J.-P., & Gaertner, D. (2008). Drifting fish aggregation devices could act as an  
1011 ecological trap for tropical tuna species. *Marine Ecology Progress Series*, 353, 255–264.  
1012 <https://doi.org/10.3354/meps07180>
- 1013 Hallier, J.-P., & Parajua, J. I. (1999). Review of tuna fisheries on floating objects in the Indian  
1014 Ocean. In M. D. Scott, W. H. Bayliff, C. E. Lennert-Cody, & K. M. Schaefer (Eds.),  
1015 *Proceedings of the International Workshop on Fishing for Tunas Associated with Floating*  
1016 *Objects* (Vol. 11, pp. 195–221). Inter-American Tropical Tuna Commission.

- 1017 Holland, K. N., Brill, R. W., & Chang, R. K. C. (1990b). Horizontal and vertical movements  
1018 of yellowfin and bigeye tuna associated with fish aggregation devices. *Fishery Bulletin*, 88(3),  
1019 494–507. [https://spo.nmfs.noaa.gov/content/horizontal-and-vertical-movements-yellowfin-](https://spo.nmfs.noaa.gov/content/horizontal-and-vertical-movements-yellowfin-and-bigeye-tuna-associated-fish-aggregating)  
1020 [and-bigeye-tuna-associated-fish-aggregating](https://spo.nmfs.noaa.gov/content/horizontal-and-vertical-movements-yellowfin-and-bigeye-tuna-associated-fish-aggregating)
- 1021 Hunsicker, M. E., Olson, R. J., Essington, T. E., Maunder, M. N., Duffy, L. M., & Kitchell, J.  
1022 F. (2012). Potential for top-down control on tropical tunas based on size structure of predator-  
1023 prey interactions. *Marine Ecology Progress Series*, 445, 263–277.  
1024 <https://doi.org/10.3354/meps09494>
- 1025 IATTC. (2021). *Resolution on the conservation measures for tropical tunas in the Eastern*  
1026 *Pacific Ocean during 2022-2024* (Resolution C-21-04). Inter-American Tropical Tuna  
1027 Commission. [https://www.iattc.org/GetAttachment/e3dc0a7e-e73c-4b8e-889e-](https://www.iattc.org/GetAttachment/e3dc0a7e-e73c-4b8e-889e-a4cd2cdd7b8b/C-21-04-Active_Tuna-conservation-in-the-EPO-2022-2024.pdf)  
1028 [a4cd2cdd7b8b/C-21-04-Active\\_Tuna-conservation-in-the-EPO-2022-2024.pdf](https://www.iattc.org/GetAttachment/e3dc0a7e-e73c-4b8e-889e-a4cd2cdd7b8b/C-21-04-Active_Tuna-conservation-in-the-EPO-2022-2024.pdf)
- 1029 ICCAT. (2022). *Recommendation by ICCAT replacing Recommendation 21-01 on a*  
1030 *multiannual conservation and management programme for tropical tunas* (Rec 22-01).  
1031 International Commission for the Conservation of Atlantic Tunas.  
1032 <https://www.iccat.int/Documents/Recs/compendiopdf-e/2022-01-e.pdf>
- 1033 Imzilen, T., Lett, C., Chassot, E., & Kaplan, D. M. (2021). Spatial management can  
1034 significantly reduce dFAD beachings in Indian and Atlantic Ocean tropical tuna purse seine  
1035 fisheries. *Biological Conservation*, 254, 108939.  
1036 <https://doi.org/10.1016/j.biocon.2020.108939>
- 1037 Imzilen, T., Lett, C., Chassot, E., Maufray, A., Goujon, M., & Kaplan, D. M. (2022).  
1038 Recovery at sea of abandoned, lost or discarded drifting fish aggregating devices. *Nature*  
1039 *Sustainability*, 1–10. <https://doi.org/10.1038/s41893-022-00883-y>
- 1040 Ioannou, C. (2017). Grouping and Predation. In T. K. Shackelford & V. A. Weekes-  
1041 Shackelford (Eds.), *Encyclopedia of Evolutionary Psychological Science*. Springer  
1042 International Publishing. [https://doi.org/10.1007/978-3-319-16999-6\\_2699-1](https://doi.org/10.1007/978-3-319-16999-6_2699-1)
- 1043 IOTC. (2019). Resolution 19/02 – Procedures on a Fish Aggregating Devices (FADs)  
1044 Management Plan. [https://www.iotc.org/cmm/resolution-1902-procedures-fish-aggregating-](https://www.iotc.org/cmm/resolution-1902-procedures-fish-aggregating-devices-fads-management-plan)  
1045 [devices-fads-management-plan](https://www.iotc.org/cmm/resolution-1902-procedures-fish-aggregating-devices-fads-management-plan)
- 1046 IOTC. (2022). *Review of data on Drifting Fish Aggregating Devices* (IOTC Ad Hoc Working  
1047 Group on FADs (WGFAD) IOTC-2022-WGFAD03-03-Rev2). Indian Ocean Tuna  
1048 Commission. <https://iotc.org/meetings/3rd-iotc-ad-hoc-working-group-fads-wgfad03>
- 1049 IOTC. (2023). *Resolution 23/02 on the management of drifting fish aggregating devices*  
1050 *(DFAD) in the IOTC area of competence*. [https://iotc.org/documents/conservation-and-](https://iotc.org/documents/conservation-and-management-measures-adopted-iotc-its-6th-special-session)  
1051 [management-measures-adopted-iotc-its-6th-special-session](https://iotc.org/documents/conservation-and-management-measures-adopted-iotc-its-6th-special-session)
- 1052 ISSF. (2014). *Report of the ISSF Workshop on FADs as Ecological Traps* (ISSF Technical  
1053 Report No. 2014-03). [https://www.issf-foundation.org/issf-downloads/download-info/issf-](https://www.issf-foundation.org/issf-downloads/download-info/issf-technical-report-2014-03-report-of-the-issf-workshop-on-fads-as-ecological-traps/)  
1054 [technical-report-2014-03-report-of-the-issf-workshop-on-fads-as-ecological-traps/](https://www.issf-foundation.org/issf-downloads/download-info/issf-technical-report-2014-03-report-of-the-issf-workshop-on-fads-as-ecological-traps/)
- 1055 Jaquemet, S., Potier, M., & Ménard, F. (2011). Do drifting and anchored Fish Aggregating  
1056 Devices (FADs) similarly influence tuna feeding habits? A case study from the western  
1057 Indian Ocean. *Fisheries Research*, 107(1), 283–290.  
1058 <https://doi.org/10.1016/j.fishres.2010.11.011>
- 1059 Justel-Rubio, A., & Recio, L. (2023). *A snapshot of the large-scale tropical tuna purse seine*  
1060 *fishing fleets as of April 2023 (Version 11)* [ISSF Technical Report 2022-14]. International  
1061 Seafood Sustainability Foundation.
- 1062 Kim, E. (2015). *Effects of Fish Aggregating Devices (FADs) on tuna movement* [PhD Thesis,  
1063 University of Hawai'i]. <https://www.soest.hawaii.edu/oceanography/PhD/2015-Kim.pdf>

- 1064 Lee, M. O., Otake, S., & Kim, J. K. (2018). Transition of artificial reefs (ARs) research and  
1065 its prospects. *Ocean & Coastal Management*, *154*, 55–65.  
1066 <https://doi.org/10.1016/j.ocecoaman.2018.01.010>
- 1067 Lennert-Cody, C. E., Moreno, G., Restrepo, V., Román, M. H., & Maunder, M. N. (2018).  
1068 Recent purse-seine FAD fishing strategies in the eastern Pacific Ocean: What is the  
1069 appropriate number of FADs at sea? *ICES Journal of Marine Science*, *75*(5), 1748–1757.  
1070 <https://doi.org/10.1093/icesjms/fsy046>
- 1071 Leroy, B., Phillips, J. S., Nicol, S., Pilling, G. M., Harley, S., Bromhead, D., Hoyle, S.,  
1072 Caillot, S., Allain, V., & Hampton, J. (2013). A critique of the ecosystem impacts of drifting  
1073 and anchored FADs use by purse-seine tuna fisheries in the Western and Central Pacific  
1074 Ocean. *Aquatic Living Resources*, *26*(1), 49–61. <https://doi.org/10.1051/alr/2012033>
- 1075 Lloret, J., Shulman, G. E., & Love, R. M. (2014). Condition and health indicators of exploited  
1076 marine fishes. Wiley Blackwell.
- 1077 Lopez, J., Moreno, G., Ibaibarriaga, L., & Dagorn, L. (2017). Diel behaviour of tuna and non-  
1078 tuna species at drifting fish aggregating devices (DFADs) in the Western Indian Ocean,  
1079 determined by fishers' echo-sounder buoys. *Marine Biology*, *164*, 44.  
1080 <https://doi.org/10.1007/s00227-017-3075-3>
- 1081 Lopez, J., Moreno, G., Sancristobal, I., & Murua, J. (2014). Evolution and current state of the  
1082 technology of echo-sounder buoys used by Spanish tropical tuna purse seiners in the Atlantic,  
1083 Indian and Pacific Oceans. *Fisheries Research*, *155*, 127–137.  
1084 <https://doi.org/10.1016/j.fishres.2014.02.033>
- 1085 Lopez, J., Roman, M. H., Lennert-Cody, C. E., Maunder, M. N., & Vogel, N. (2021).  
1086 *Floating-object fishery indicators: A 2020 report* (FAD-05-INF-C). Inter-American Tropical  
1087 Tuna Commission. [https://www.iattc.org/getattachment/70b8d0d7-1639-42a5-b7d8-  
1088 490f4a12f197/FAD-05a-INF-C\\_Floating-object-fishery-indicators-a-2020-report.pdf](https://www.iattc.org/getattachment/70b8d0d7-1639-42a5-b7d8-490f4a12f197/FAD-05a-INF-C_Floating-object-fishery-indicators-a-2020-report.pdf)
- 1089 Machful, P., Portal, A., Macdonald, J., Allain, V., Phillips, J. S., & Nicol, S. (2021). Tuna  
1090 stomachs: Is the glass half full, or half empty? *SPC Fisheries Newsletter*, *166*, 38–44.
- 1091 Malone, M. A., Buck, K. M., Moreno, G., & Sancho, G. (2011). Diet of three large pelagic  
1092 fishes associated with drifting fish aggregating devices (DFADs) in the western equatorial  
1093 Indian Ocean. *Animal Biodiversity and Conservation*, *34*(2), 287–294.  
1094 <https://doi.org/10.32800/abc.2011.34.0287>
- 1095 Marsac, F., Fonteneau, A., & Ménard, F. (2000). Drifting FADs used in tuna fisheries: An  
1096 ecological trap? *Pêche Thonière et Dispositifs de Concentration de Poissons*, *28*, 537–552.
- 1097 Marsac, F., Fonteneau, A., & Michaud, A. (2014). *L'or bleu des Seychelles: Histoire de la*  
1098 *pêche industrielle au thon dans l'océan Indien*.  
1099 <https://doi.org/10.4000/BOOKS.IRDEDITIONS.9700>
- 1100 Matsumoto, T., Satoh, K., Semba, Y., & Toyonaga, M. (2016). Comparison of the behavior of  
1101 skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna  
1102 associated with drifting FADs in the equatorial central Pacific Ocean. *Fisheries*  
1103 *Oceanography*, *25*(6), 565–581. <https://doi.org/10.1111/fog.12173>
- 1104 Matsumoto, T., Satoh, K., & Toyonaga, M. (2014). Behavior of skipjack tuna (*Katsuwonus*  
1105 *pelamis*) associated with a drifting FAD monitored with ultrasonic transmitters in the  
1106 equatorial central Pacific Ocean. *Fisheries Research*, *157*, 78–85.  
1107 <https://doi.org/10.1016/j.fishres.2014.03.023>
- 1108 Maufroy, A., Chassot, E., Joo, R., & Kaplan, D. M. (2015). Large-Scale Examination of  
1109 Spatio-Temporal Patterns of Drifting Fish Aggregating Devices (dFADs) from Tropical Tuna

- 1110 Fisheries of the Indian and Atlantic Oceans. *PLOS ONE*, 10(5), e0128023.  
1111 <https://doi.org/10.1371/journal.pone.0128023>
- 1112 Maufroy, A., Kaplan, D. M., Bez, N., De Molina, A. D., Murua, H., Floch, L., & Chassot, E.  
1113 (2017). Massive increase in the use of drifting Fish Aggregating Devices (dFADs) by tropical  
1114 tuna purse seine fisheries in the Atlantic and Indian oceans. *ICES Journal of Marine Science*,  
1115 74(1), 215–225. <https://doi.org/10.1093/icesjms/fsw175>
- 1116 Maury, O. (2017). Can schooling regulate marine populations and ecosystems? Progress in  
1117 Oceanography, 156, 91–103. <https://doi.org/10.1016/j.pocean.2017.06.003>
- 1118 Ménard, F., Stéquert, B., Rubin, A., Herrera, M., & Marchal, É. (2000). Food consumption of  
1119 tuna in the Equatorial Atlantic ocean: FAD-associated versus unassociated schools. *Aquatic*  
1120 *Living Resources*, 13(4), 233–240. [https://doi.org/10.1016/S0990-7440\(00\)01066-4](https://doi.org/10.1016/S0990-7440(00)01066-4)
- 1121 Mitsunaga, Y., Endo, C., Anraku, K., Selorio, C. M., & Babaran, R. P. (2012). Association of  
1122 early juvenile yellowfin tuna *Thunnus albacares* with a network of payaos in the Philippines.  
1123 *Fisheries Science*, 78(1), 15–22. <https://doi.org/10.1007/s12562-011-0431-y>
- 1124 Miyake, M., Guillotreau, P., Sun, C., & Ishimura, G. (Eds.). (2010). *Recent developments in*  
1125 *the tuna industry: Stocks, fisheries, management, processing, trade and markets*. Food and  
1126 Agriculture Organization of the United Nations.
- 1127 Moreno, G., Boyra, G., Sancristobal, I., Itano, D., & Restrepo, V. (2019). Towards acoustic  
1128 discrimination of tropical tuna associated with Fish Aggregating Devices. *PLoS ONE*, 14(6),  
1129 e0216353. <https://doi.org/10.1371/journal.pone.0216353>
- 1130 Moreno, G., Dagorn, L., Sancho, G., & Itano, D. (2007). Fish behaviour from fishers’  
1131 knowledge: The case study of tropical tuna around drifting fish aggregating devices (DFADs).  
1132 *Canadian Journal of Fisheries and Aquatic Sciences*, 64(11), 1517–1528.  
1133 <https://doi.org/10.1139/f07-113>
- 1134 Morón, J. (2001). *Report on Management Measures for the European Tuna Purse Seine*  
1135 *Fleet*. Working Paper for the Standing Committee on Tuna and Billfish (SCTB14).
- 1136 Mullu, D. (2016). A review on the effect of habitat fragmentation on ecosystem. *Journal of*  
1137 *Natural Sciences Research*, 6(15), 1–15.
- 1138 Nooteboom, P. D., Scutt Phillips, J., Kehl, C., Nicol, S., & van Sebille, E. (2023). Modelling  
1139 of tuna around fish aggregating devices: The importance of ocean flow and prey. *Ecological*  
1140 *Modelling*, 475, 110188. <https://doi.org/10.1016/j.ecolmodel.2022.110188>
- 1141 Ohta, I., & Kakuma, S. (2005). Periodic behavior and residence time of yellowfin and bigeye  
1142 tuna associated with fish aggregating devices around Okinawa Islands, as identified with  
1143 automated listening stations. *Marine Biology*, 146(3), 581–594.  
1144 <https://doi.org/10.1007/s00227-004-1456-x>
- 1145 Orue, B., Lopez, J., Pennino, M. G., Moreno, G., Santiago, J., & Murua, H. (2020).  
1146 Comparing the distribution of tropical tuna associated with drifting fish aggregating devices  
1147 (DFADs) resulting from catch dependent and independent data. *Deep Sea Research Part II:*  
1148 *Topical Studies in Oceanography*, 104747. <https://doi.org/10.1016/j.dsr2.2020.104747>
- 1149 Pérez, G., Dagorn, L., Deneubourg, J.-L., Forget, F., Filmalter, J. D., Holland, K., Itano, D.,  
1150 Adam, S., Jauharee, R., Beeharry, S. P., & Capello, M. (2020). Effects of habitat  
1151 modifications on the movement behavior of animals: The case study of Fish Aggregating  
1152 Devices (FADs) and tropical tunas. *Movement Ecology*, 8(1), 47.  
1153 <https://doi.org/10.1186/s40462-020-00230-w>
- 1154 Pérez, G., Dupaix, A., Dagorn, L., Deneubourg, J.-L., Holland, K., Beeharry, S., & Capello,  
1155 M. (2022). Correlated Random Walk of tuna in arrays of Fish Aggregating Devices: A field-

- 1156 based model from passive acoustic tagging. *Ecological Modelling*, 470, 110006.  
1157 <https://doi.org/10.1016/j.ecolmodel.2022.110006>
- 1158 Phillips, J. S., Escalle, L., Pilling, G., Gupta, A. S., & Seville, E. van. (2019a). Regional  
1159 connectivity and spatial densities of drifting fish aggregating devices, simulated from fishing  
1160 events in the Western and Central Pacific Ocean. *Environmental Research Communications*,  
1161 1(5), 055001. <https://doi.org/10.1088/2515-7620/ab21e9>
- 1162 Phillips, J. S., Peatman, T., Escalle, L., Leroy, B., & Smith, N. (2019b). *Electronic tagging*  
1163 *for the mitigation of bigeye and yellowfin tuna juveniles by purse seine fisheries* (15th Regular  
1164 Session of the Scientific Commity No. SC15-EB-WP-08). Western and Central Pacific  
1165 Fisheries Commission. <https://meetings.wcpfc.int/index.php/node/11299>
- 1166 Phillips, J. S., Pilling, G. M., Leroy, B., Evans, K., Usu, T., Lam, C. H., Schaefer, K. M., &  
1167 Nicol, S. (2017). Revisiting the vulnerability of juvenile bigeye (*Thunnus obesus*) and  
1168 yellowfin (*T. albacares*) tuna caught by purse-seine fisheries while associating with surface  
1169 waters and floating objects. *PloS One*, 12(6), e0179045.  
1170 <https://doi.org/10.1371/journal.pone.0179045>
- 1171 Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P.,  
1172 Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel,  
1173 M., McAllister, M. K., Pope, J., & Sainsbury, K. J. (2004). Ecosystem-Based Fishery  
1174 Management. *Science*, 305(5682), 346–347. <https://doi.org/10.1126/science.1098222>
- 1175 Pons, M., Kaplan, D., Moreno, G., Escalle, L., Abascal, F., Hall, M., Restrepo, V., & Hilborn,  
1176 R. (2023). Benefits, concerns, and solutions of fishing for tunas with drifting fish aggregation  
1177 devices. *Fish and Fisheries*, n/a(n/a). <https://doi.org/10.1111/faf.12780>
- 1178 Potier, M., Marsac, F., Cherel, Y., Lucas, V., Sabatié, R., Maury, O., & Ménard, F. (2007).  
1179 Forage fauna in the diet of three large pelagic fishes (lancetfish, swordfish and yellowfin  
1180 tuna) in the western equatorial Indian Ocean. *Fisheries Research*, 83(1), 60–72.  
1181 <https://doi.org/10.1016/j.fishres.2006.08.020>
- 1182 Potier, M., Marsac, F., Lucas, V., Sabatié, R., Hallier, J.-P., & Ménard, F. (2004). Feeding  
1183 partitioning among tuna taken in surface and mid-water layers: The case of yellowfin  
1184 (*Thunnus albacares*) and bigeye (*T. obesus*) in the western tropical Indian Ocean. *Western*  
1185 *Indian Ocean Journal of Marine Science*, 3(1), 51–62.
- 1186 Proctor, C., Hobart, & Tasmania. (2019). Project final report developing research capacity for  
1187 management of Indonesia’s pelagic fisheries resources—Final report. *ACIAR Final Reports*,  
1188 *FR2019/01*. <https://www.cabdirect.org/cabdirect/abstract/20203534645>
- 1189 Ramos, M. L., Delgado de Molina, A., & Ariz, J. (2010). *Analysis of activity data obtained*  
1190 *from supply vessel’s logbooks implemented by the Spanish fleet and associated in Indian*  
1191 *Ocean* (Working Party on Tropical Tunas (WPTT), pp. 18–25). Indian Ocean Tuna  
1192 Commission. [https://iotc.org/documents/analysis-activity-data-obtained-supply-vessels-](https://iotc.org/documents/analysis-activity-data-obtained-supply-vessels-logbooks-implemented-spanish-fleet-and)  
1193 [logbooks-implemented-spanish-fleet-and](https://iotc.org/documents/analysis-activity-data-obtained-supply-vessels-logbooks-implemented-spanish-fleet-and)
- 1194 Restrepo, V., Dagorn, L., Itano, D., Justel-Rubio, A., Forget, F., & Moreno, G. (2017). A  
1195 Summary of Bycatch Issues and ISSF Mitigation Activities to date in purse seine fisheries,  
1196 with emphasis on FADs. *ISSF Technical Reports*, 41.
- 1197 Robert, M., Dagorn, L., Bodin, N., Pernet, F., Arsenault-Pernet, E.-J., & Deneubourg, J.-L.  
1198 (2014). Comparison of condition factors of skipjack tuna (*Katsuwonus pelamis*) associated or  
1199 or not with floating objects in an area known to be naturally enriched with logs. *Canadian*  
1200 *Journal of Fisheries and Aquatic Sciences*. <https://doi.org/10.1139/cjfas-2013-0389>
- 1201 Robert, M., Dagorn, L., Deneubourg, J. L., Itano, D., & Holland, K. (2012). Size-dependent  
1202 behavior of tuna in an array of fish aggregating devices (FADs). *Marine Biology*, 159(4),  
1203 907–914. <https://doi.org/10.1007/s00227-011-1868-3>

- 1204 Robert, M., Dagorn, L., Filmlalter, J. D., Deneubourg, J.-L., Itano, D., & Holland, K. (2013).  
1205 Intra-individual behavioral variability displayed by tuna at fish aggregating devices (FADs).  
1206 *Marine Ecology Progress Series*, 484, 239–247. <https://doi.org/10.3354/meps10303>
- 1207 Robert, M., Dagorn, L., Lopez, J., Moreno, G., & Deneubourg, J.-L. (2013). Does social  
1208 behavior influence the dynamics of aggregations formed by tropical tunas around floating  
1209 objects? An experimental approach. *Journal of Experimental Marine Biology and Ecology*,  
1210 440, 238–243. <https://doi.org/10.1016/j.jembe.2013.01.005>
- 1211 Robertson, B. A., & Hutto, R. L. (2006). A framework for understanding ecological traps and  
1212 an evaluation of existing evidence. *Ecology*, 87(5), 1075–1085. [https://doi.org/10.1890/0012-9658\(2006\)87\[1075:AFFUET\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2006)87[1075:AFFUET]2.0.CO;2)
- 1214 Rodriguez-Tress, P., Capello, M., Forget, F., Soria, M., Beeharry, S. P., Dussooa, N., &  
1215 Dagorn, L. (2017). Associative behavior of yellowfin *Thunnus albacares*, skipjack  
1216 *Katsuwonus pelamis*, and bigeye tuna *T. obesus* at anchored fish aggregating devices (FADs)  
1217 off the coast of Mauritius. *Marine Ecology Progress Series*, 570, 213–222.  
1218 <https://doi.org/10.3354/meps12101>
- 1219 Rubenstein, D. I. (1978). On Predation, Competition, and the Advantages of Group Living. In  
1220 P. P. G. Bateson & P. H. Klopfer (Eds.), *Social Behavior* (pp. 205–231). Springer US.  
1221 [https://doi.org/10.1007/978-1-4684-2901-5\\_9](https://doi.org/10.1007/978-1-4684-2901-5_9)
- 1222 Sardenne, F., Chassot, E., Fouché, E., Ménard, F., Lucas, V., & Bodin, N. (2016). Are  
1223 condition factors powerful proxies of energy content in wild tropical tunas? *Ecological*  
1224 *Indicators*, 71, 467–476. <https://doi.org/10.1016/j.ecolind.2016.06.031>
- 1225 Schaefer, K. M., Fuller, D., Hampton, J., Caillot, S., Leroy, B., & Itano, D. (2015).  
1226 Movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus*) tagged and released in  
1227 the equatorial Central Pacific Ocean, with conventional and archival tags. *Fisheries Research*,  
1228 161, 336–355. <https://doi.org/10.1016/j.fishres.2014.08.018>
- 1229 Schaefer, K. M., & Fuller, D. W. (2002). Movements, behavior, and habitat selection of  
1230 bigeye tuna (*Thunnus obesus*) in the eastern equatorial Pacific, ascertained through archival  
1231 tags. *Fishery Bulletin*, 100(4), 765–788.
- 1232 Schaefer, K. M., & Fuller, D. W. (2010). Vertical movements, behavior, and habitat of bigeye  
1233 tuna (*Thunnus obesus*) in the equatorial eastern Pacific Ocean, ascertained from archival tag  
1234 data. *Marine Biology*, 157(12), 2625–2642. <https://doi.org/10.1007/s00227-010-1524-3>
- 1235 Schaefer, K. M., & Fuller, D. W. (2013). Simultaneous behavior of skipjack (*Katsuwonus*  
1236 *pelamis*), bigeye (*Thunnus obesus*), and yellowfin (*T. albacares*) tunas, within large multi-  
1237 species aggregations associated with drifting fish aggregating devices (FADs) in the  
1238 equatorial eastern Pacific Ocean. *Marine Biology*, 160(11), 3005–3014.  
1239 <https://doi.org/10.1007/s00227-013-2290-9>
- 1240 Schaefer, K. M., & Fuller, D. W. (2019). Spatiotemporal variability in the reproductive  
1241 dynamics of Skipjack Tuna (*Katsuwonus pelamis*) in the eastern Pacific Ocean. *Fisheries*  
1242 *Research*, 209, 1–13. <https://doi.org/10.1016/j.fishres.2018.09.002>
- 1243 Schaefer, K. M., Fuller, D. W., & Block, B. A. (2009). Vertical movements and habitat  
1244 utilization of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye  
1245 (*Thunnus obesus*) tunas in the equatorial eastern Pacific Ocean, ascertained through archival  
1246 tag data. In *Tagging and tracking of marine animals with electronic devices* (pp. 121–144).  
1247 Springer.
- 1248 Schlaepfer, M. A., Runge, M. C., & Sherman, P. W. (2002). Ecological and evolutionary  
1249 traps. *Trends in Ecology & Evolution*, 17(10), 474–480. [https://doi.org/10.1016/S0169-5347\(02\)02580-6](https://doi.org/10.1016/S0169-5347(02)02580-6)
- 1250



- 1251 Scott, G. P., & Lopez, J. (2014). *The Use of Fads in Tuna Fisheries*. Directorate General for  
1252 Internal Policies, European Parliament, Committee in Fisheries.  
1253 [https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL-  
PECH\\_NT\(2014\)514002](https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL-<br/>1254 PECH_NT(2014)514002)
- 1255 Scott, M. D., Bayliff, W. H., Lennert-Cody, C. E., & Schaefer, K. M. (1999). Proceedings of  
1256 the international workshop on the ecology and fisheries for tunas associated with floating  
1257 objects. *Inter-American Tropical Tuna Commission Special Report, 11*, 478.  
1258 <http://hdl.handle.net/1834/23201>
- 1259 Sempo, G., Dagorn, L., Robert, M., & Deneubourg, J.-L. (2013). Impact of increasing  
1260 deployment of artificial floating objects on the spatial distribution of social fish species.  
1261 *Journal of Applied Ecology, 50*(5), 1081–1092. <https://doi.org/10.1111/1365-2664.12140>
- 1262 Sherley, R. B., Ludynia, K., Dyer, B. M., Lamont, T., Makhado, A. B., Roux, J.-P., Scales, K.  
1263 L., Underhill, L. G., & Votier, S. C. (2017). Metapopulation Tracking Juvenile Penguins  
1264 Reveals an Ecosystem-wide Ecological Trap. *Current Biology, 27*(4), 563–568.  
1265 <https://doi.org/10.1016/j.cub.2016.12.054>
- 1266 Sobradillo, B., Boyra, G., Uranga, J., & Moreno, G. (2023). *TS measurments of ex-situ*  
1267 *yellowfin tuna (Thunnus albacares) and frequency-response discrimination for tropical tuna*  
1268 *species* [7th Meeting of the Ad Hoc Working Group on FADs]. Inter-American Tropical Tuna  
1269 Commission. [https://www.iattc.org/GetAttachment/01c4217f-4f28-4c34-b6e6-  
e5bb7efd777e/FAD-07-MISC\\_Acoustic-discrimination-of-juvenile-yellowfin-tuna-in-an-  
offshore-cage.pdf](https://www.iattc.org/GetAttachment/01c4217f-4f28-4c34-b6e6-<br/>1270 e5bb7efd777e/FAD-07-MISC_Acoustic-discrimination-of-juvenile-yellowfin-tuna-in-an-<br/>1271 offshore-cage.pdf)
- 1272 Song, L., & Shen, H. (2022). An integrated scheme for the management of drifting fish  
1273 aggregating devices in tuna purse seine fisheries. *Fisheries Management and Ecology, 30*(1),  
1274 56–69. <https://doi.org/10.1111/fme.12600>
- 1275 Stehfest, K. M., & Dagorn, L. (2010). *Differences in large-scale movement between free*  
1276 *swimming and fish aggregating device (FAD) caught tuna* (Working Party on Tropical Tuna  
1277 IOTC-2010-WPTT-06; p. 24). Indian Ocean Tuna Commission.  
1278 <https://iotc.org/meetings/12th-session-working-party-tropical-tunas>
- 1279 Stéquert, B., & Marsac, F. (1986). *La pêche de surface des thonidés tropicaux dans l’Océan*  
1280 *Indien*. Food & Agriculture Org.
- 1281 Swearer, S. E., Morris, R. L., Barrett, L. T., Sievers, M., Dempster, T., & Hale, R. (2021). An  
1282 overview of ecological traps in marine ecosystems. *Frontiers in Ecology and the*  
1283 *Environment, 19*(4), 234–242. <https://doi.org/10.1002/fee.2322>
- 1284 Taquet, M. (2013). Fish aggregating devices (FADs): Good or bad fishing tools? A question  
1285 of scale and knowledge. *Aquatic Living Resources, 26*(1), 25–35.  
1286 <https://doi.org/10.1051/alr/2013043>
- 1287 Teske, P. R., Emami-Khoyi, A., Golla, T. R., Sandoval-Castillo, J., Lamont, T., Chiazzari, B.,  
1288 McQuaid, C. D., Beheregaray, L. B., & van der Lingen, C. D. (2021). The sardine run in  
1289 southeastern Africa is a mass migration into an ecological trap. *Science Advances, 7*(38),  
1290 eabf4514. <https://doi.org/10.1126/sciadv.abf4514>
- 1291 Thiel, M., & Gutow, L. (2005). The ecology of rafting in the marine environment. I. The  
1292 floating substrata. *Oceanography and Marine Biology: An Annual Review, 42*, 181–264.
- 1293 Tolotti, M. T., Forget, F., Capello, M., Filmalter, J. D., Hutchinson, M., Itano, D., Holland,  
1294 K., & Dagorn, L. (2020). Association dynamics of tuna and purse seine bycatch species with  
1295 drifting fish aggregating devices (FADs) in the tropical eastern Atlantic Ocean. *Fisheries*  
1296 *Research, 226*, 105521. <https://doi.org/10.1016/j.fishres.2020.105521>

- 1297 Wain, G., Guéry, L., Kaplan, D. M., & Gaertner, D. (2021). Quantifying the increase in  
1298 fishing efficiency due to the use of drifting FADs equipped with echosounders in tropical tuna  
1299 purse seine fisheries. *ICES Journal of Marine Science*, 78(1), 235–245.  
1300 <https://doi.org/10.1093/icesjms/fsaa216>
- 1301 Wang, X., Chen, Y., Truesdell, S., Xu, L., Cao, J., & Guan, W. (2014). The large-scale  
1302 deployment of fish aggregation devices alters environmentally-based migratory behavior of  
1303 skipjack tuna in the Western Pacific Ocean. *PLoS One*, 9(5), e98226.  
1304 <https://doi.org/10.1371/journal.pone.0098226>
- 1305 Wang, X., Xu, L., Chen, Y., Zhu, G., Tian, S., & Zhu, J. (2012). Impacts of fish aggregation  
1306 devices on size structures of skipjack tuna *Katsuwonus pelamis*. *Aquatic Ecology*, 46(3), 343–  
1307 352. <https://doi.org/10.1007/s10452-012-9405-0>
- 1308 WCPFC. (2021). *Conservation and Management Measure for bigeye, yellowfin and skipjack*  
1309 *tuna in the Western and Central Pacific Ocean* (CMM-2021–01). Western and Central Pacific  
1310 Fisheries Commission. [https://www.wcpfc.int/doc/cmm-2018-01/conservation-and-](https://www.wcpfc.int/doc/cmm-2018-01/conservation-and-management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and)  
1311 [management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and](https://www.wcpfc.int/doc/cmm-2018-01/conservation-and-management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and)
- 1312 Weng, J.-S., Hung, M.-K., Lai, C.-C., Wu, L.-J., Lee, M.-A., & Liu, K.-M. (2013). Fine-scale  
1313 vertical and horizontal movements of juvenile yellowfin tuna (*Thunnus albacares*) associated  
1314 with a subsurface fish aggregating device (FAD) off southwestern Taiwan. *Journal of Applied*  
1315 *Ichthyology*, 29(5), 990–1000. <https://doi.org/10.1111/jai.12265>
- 1316 Zudaire, I., Murua, H., Grande, M., Goñi, N., Potier, M., Ménard, F., Chassot, E., & Bodin,  
1317 N. (2015). Variations in the diet and stable isotope ratios during the ovarian development of  
1318 female yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. *Marine Biology*,  
1319 162(12), 2363–2377. <https://doi.org/10.1007/s00227-015-2763-0>
- 1320 Zudaire, I., Murua, H., Grande, M., Pernet, F., & Bodin, N. (2014). Accumulation and  
1321 mobilization of lipids in relation to reproduction of yellowfin tuna (*Thunnus albacares*) in the  
1322 Western Indian Ocean. *Fisheries Research*, 160, 50–59.  
1323 <https://doi.org/10.1016/j.fishres.2013.12.010>

1324 **Tables**

1325 **Table 1: Summary of main findings from previous studies on the numbers of**  
 1326 **monitored floating objects or the number of DFADs used in large-scale tropical tuna**  
 1327 **purse seine fisheries.**

<b>Area</b>	<b>Period</b>	<b>Indicator</b>	<b>Associated number of vessels</b>	<b>Estimation</b>	<b>Reference</b>
All oceans	2006-2011	DFADs deployed yearly		47,000- 103,000	Baske et al. (2012)
	2010s	DFADs deployed yearly		91,000	Scott & Lopez (2014)
	2013	DFADs deployed yearly		81,000- 121,000	Gershman et al. (2015)
Atlantic Ocean	1998	Radio buoys	45 vessels	3,000	Ménard et al. (2000)
	2004-2014	Buoys deployed yearly	Per vessel (French PS fleet)	From 41 (2004) to 200 (2014)	Fonteneau et al. (2015)
	2007-2013	Monthly active buoys		From 1,289 (2007) to 8,856 (2013)	Maufroy et al. (2017)

Indian Ocean	2003-2005	Daily active buoys	45 vessels	2,100	Moreno et al. (2007)
	2007-2013	Monthly active buoys		From 2,679 (2007) to 10,929 (2013)	Maufroy et al. (2017)
	2010-2012	Daily active buoys	34 vessels	3,750-7,500	Filmalter et al. (2013)
	2010-2014	Quarterly active buoys	25 vessels	1,200	Chassot et al. (2014)
	2013	Quarterly active buoys	19 vessels	6,015	Delgado de Molina et al. (2014)
	2013	DFADs deployed yearly	19 vessels	12,813	Delgado de Molina et al. (2014)
	2016-2021	DFADs deployed yearly	Whole ocean	10,514 to 24,550	to IOTC (2022)
Western and Central Pacific Ocean	2011-2019	Daily active buoys	Per vessel	45-75	Escalle et al. (2021)
	2011-2019	DFADs deployed	268 to 322 vessels	20,000-40,000	Escalle et al. (2020, 2021a)

		yearly	(whole WCPO)			
	2016-2019	Buoys deployed yearly	Whole WCPO	31,000	39,500	to Escalle et al. (2020)
	2016-2020	Buoys deployed yearly	187 to 235 vessels	16,000	22,000	to Escalle et al. (2021b)
Eastern Pacific Ocean	2018-2020	Daily active buoys	100 to 140 vessels	8,000-11,000		Lopez et al. (2021)
	2015-2020	DFADs deployed yearly	100 to 140 vessels	20,000	40,000	to Lopez et al. (2021)

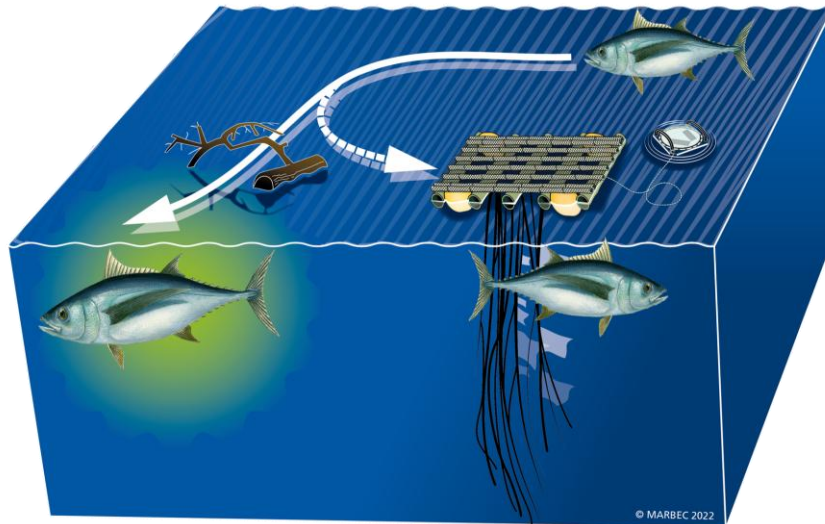
1328 **Table 2: Summary of main findings from previous studies on tuna individual CRT and CAT assessed under anchored and drifting FADs.**  
 1329 CRT: Continuous Residence Time – continuous bouts of time spent at the same FAD without any absence longer than 24h. CAT: Continuous Absence  
 1330 Time – the time between two associations with a FAD. FL: fork length, YFT: *Thunnus albacares*, SKJ: *Katsuwonus pelamis*, BET: *Thunnus obesus*).

1331

FAD type	Study location	Metric	Findings	Reference	
Drifting	Eastern Atlantic Ocean	CRT	YFT (34-82 cm FL): average of 19.15 days (maximum value of 55 days) SKJ (39-61 cm FL): average of 9.19 days (maximum value of 15 days) BET (45-61 cm FL): average of 25.31 days (maximum value of 55 days)	Tolotti et al. (2020)	
	Mozambique Chanel (Western Indian Ocean)	CRT	YFT (29-60 cm FL): between 0.00-26.72 days with median at 9.98 days SKJ (47-57 cm FL): between 0.09-18.33 days with median at 4.47days BET (54-56 cm FL): between 0.00-6.56 days with median at 3.89 days	Govinden et al. (2010)	
	Western and Central Pacific Ocean	CRT	SKJ (46-60 cm FL): median of 1 day (maximum value of 18 days) YFT (36-98 cm FL): median of 2 days (maximum value of 50 days) BET (38-90 cm FL): median of 10 days (maximum value of 30 days)	Phillips et al. (2019b)	
		CAT	BET (38-90 cm FL): median of 3.2 days (maximum value of 48.2 days)		
	Equatorial Central Pacific Ocean	CRT	SKJ (36-65 cm FL) : from 0.0 to 6.4 days (with average value at 2.3 days)	Matsumoto et al. (2014)	
		CRT	SKJ (34.5–65.0 cm FL): less than 7 days YFT (31.6–93.5 cm FL): less than 7 days BET (33.5–85.5 cm FL): less than 7 days	Matsumoto et al. (2016)	
	Anchored	Philippines (Indian Ocean)	CRT	Juvenile YFT (19–31 cm FL) : between 1 and 6 days	Mitsunaga et al., (2012)
		Maldives Islands (Indian Ocean)	CRT	SKJ (37–54 cm FL) : 0.20-3.75 days YFT (35–53 cm FL) : 0.61-0.70 days	Govinden et al. (2013)
		Mauritius islands (Indian Ocean)	CRT	SKJ (41 -59 cm FL) : 2.5 days YFT (46 -81cm FL) : 9.6 days BET (48 - 60 cm FL) : 5.2 days	Rodriguez-Tress et al. (2017)
CAT			SKJ (41 -59 cm FL) : 2.9 days YFT (46 -81cm FL) : 1.4 days BET (48 - 60 cm FL) : 0.8 days		
Hawaii islands		CRT	Small YFT (30-39 cm FL) : 13.58 days	Robert et al. (2012)	

(Pacific Ocean)		Large YFT (63-68 cm FL): 9.44 days	
	CAT	4 days for small YFT and 1.65 days for large YFT	
	CRT	4 behavioural modes reported for YFT (54 to 95 cm FL) : - Brief association : 13.1 minutes - Short association: 2.9 days - Two long association modes : 13.8 and 23.2 days	Robert et al. (2013a)
	CAT	2 behavioural modes: - Short: 2.8 days - Long: infinite	
South-western Taiwan (Pacific Ocean)	CRT	YFT (35–81 cm FL) : average of 2.1 days (maximum value to 31 days)	Weng et al. (2013)
Okinawa Island (Pacific Ocean)	CRT	YFT (40-119 cm FL): median of 7.9 days (maximum value to 55 days) BET (50-77 cm FL): median of 7.0 days (maximum value to 34 days)	Ohta & Kakuma (2005)
Palau Islands (Pacific Ocean)	CRT	YFT (50-60cm FL): mean of 16 days (maximum value to 123 days) YFT (60-100cm FL): mean of 2 days (maximum value to 33 days)	Filous et al., (2020)

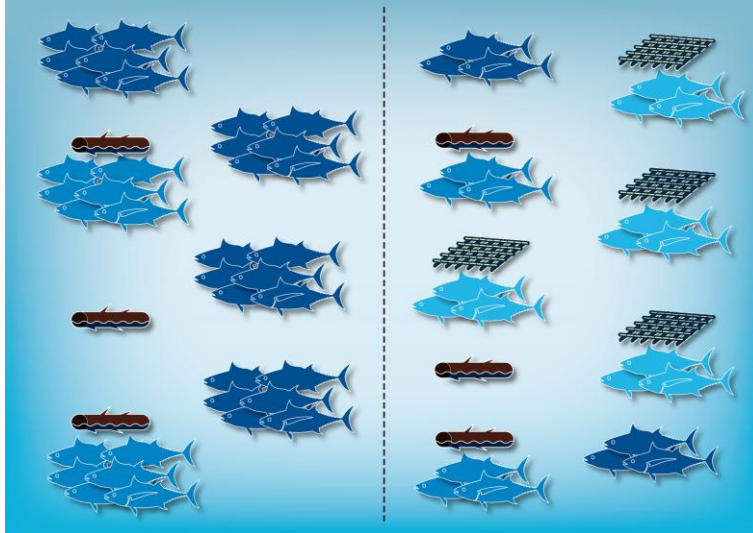
1332  
1333  
1334  
1335  
1336



1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346

**Figure 1: Schematic representation of the ecological trap hypothesis applied to Drifting Fish Aggregating Devices (DFADs), as originally formulated.** Under this hypothesis, before DFADs introduction, when only natural floating objects (NLOGs) were present, floating objects were indicators of productive areas. Hence, by associating with floating objects, tuna selected high quality habitats. DFAD massive deployment modified the distribution of floating objects (FOBs), which are not representative of rich areas anymore. By associating with FOBs, tunas can be attracted to or retained in habitats of lesser quality.





1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355

**Figure 2: Schematic representation of potential effects of Drifting Fish Aggregating Devices (DFADs) on tuna schooling behaviour. The left side represents an ocean with natural floating objects (NLOGs) only (no DFAD), while the right side represents an ocean with both NLOGs and DFADs, i.e. more floating objects (FOBs). Dark blue represents tuna in free-swimming schools, intermediate blue tuna associated with NLOGs and light blue tuna associated with DFADs. An increase in FOB density (right panel) could lead both to (i) more tuna associated to FOBs and less free-swimming schools, (ii) more numerous but smaller FOB-associated schools.**