Patagonian toothfish bycatch in the calamari trawl fishery (2012 - 2021)

Skeljo F

Fisheries Department
Directorate of Natural Resources
Falkland Islands Government
Stanley, Falkland Islands

20 April 2023

BY – 2023 – TOO

DESIRE THE RIGHT

Participating Scientific Staff

Frane Skeljo (PhD, Stock Assessment Scientist)

Comments provided by: Andreas Winter (PhD, Senior Stock Assessment Scientist)
Alexander Arkhipkin (PhD, Senior Fisheries Scientist)
Brendon Lee (PhD, Fisheries Scientist)

Acknowledgements

I thank all of the observers and researchers that have contributed to the data used in this report. I also thank Brendon Lee, Toni Trevizan and Alex Blake for useful discussion about this topic.

For citation purposes this publication should be referenced as follows:

Skeljo F. 2023. Patagonian toothfish (*Dissostichus eleginoides*) bycatch in the calamari trawl fishery (2012 - 2021). Fisheries Report BY-2023-TOO. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 50 p.

Distribution: Public Domain

Reviewed and approved by:

Andrea Clausen
Director of Natural Resources

Date: 20 April 2023

Table of Contents

Summary 1
1. Introduction 2
2. Material and Methods 3
    2.1. Data 3
    2.2. Move-on rule analysis 4
3. Results and Discussion 6
    3.1. Toothfish bycatch overview 6
    3.2. Toothfish bycatch size-structure 9
    3.3. Toothfish bycatch monitoring and reporting 11
    3.4. Toothfish bycatch move-on rule 26
4. Conclusions 37
5. Recommendations 38
6. References 40

Appendix 1……… 41
Appendix 2……….. 49

Summary

1. This report synthesizes the available data on juvenile toothfish bycatch in the calamari trawl fishery during the last 10 years (2012-2021), and provides an overview of toothfish bycatch trends, reporting practices, and management measures.
2. Toothfish bycatch was generally low in the calamari trawl fishery during the last ten years (<10 t annually) but peaked in 2016-2017, following the recruitment of a strong toothfish cohort into the fishery in 2015.
3. Toothfish bycatch monitoring and reporting practices in the calamari trawl fishery went through three distinct phases over the last ten years; from low monitoring and infrequent reporting (only large catches) in 2012-2015, through increased catches, monitoring and reporting during 2016-2017, to intensive monitoring and frequent reporting (even the smallest catches) in 2018-2021.
4. A contract observer programme was introduced in 2018 and contributed considerably to the toothfish monitoring effort. A comparison of fishery self-reported and observed data revealed some discrepancies; recommendations were made on potential improvements to data management, contract observer protocols, and the fishery self-reporting protocol.
5. Since 2018, toothfish bycatch in trawl fisheries was regulated via a move-on rule with a 1.5% bycatch threshold. Evaluating the effectiveness of this rule in the context of the calamari trawl fishery proved difficult because it was introduced in a period of low toothfish recruitment and appears to have never been triggered. As an alternative solution, a range of potential move-on rule thresholds appropriate for the calamari fishery were analysed.
6. Toothfish appear in the calamari trawl fishery already when ~0.5 years old; because of their small size, these fish contribute very little towards the bycatch weight, and a weight-based move-on rule likely won't have a desired conservation effect. A small-scale spatio-temporal closure is suggested as an alternative solution during years with strong toothfish recruitment.

1. Introduction

Patagonian toothfish (*Dissostichus eleginoides*; hereafter toothfish) is a large notothenioid fish found on the shelves and slopes of South America and around the sub-Antarctic islands of the Southern Ocean. In the Falkland Islands waters, toothfish spawn on the slopes of Burdwood Bank at ca. 1000 m depth with a minor peak in May, and a major peak from July to August (Laptikhovsky *et al.* 2006). The eggs, larvae, and small juveniles (<10 cm TL) develop and grow in epipelagic layers of the Falkland Current, with early juveniles of 10-12 cm TL (<1 year old; Lee 2017) occurring on the Patagonian shelf at depths ~100 m (Arkhipkin and Laptikhovsky 2010). Immature toothfish remain on the shelf for 3-4 years and then undertake a characteristic ontogenetic migration into deeper waters where adults reside and spawn (Arkhipkin and Laptikhovsky, 2010).

In the Falkland Islands, a Marine Stewardship Council (MSC) certified longline fishery targets the adult component of the population in deep waters between 800 and 2000 m (Lee *et al.* 2021). However, notable quantities of juvenile toothfish are taken as bycatch in the shelf-based (<400 m depth) finfish and calamari trawl fisheries (Laptikhovsky and Brickle 2005, Randhawa 2020). In the finfish fishery toothfish is a commercially valuable bycatch, while in the calamari fishery it is usually discarded, due to the small size of the specimens (the calamari trawls are permitted to use fine mesh liners). Therefore, juvenile toothfish bycatch in the calamari trawl fishery is a waste of their potential commercial value as well as an impact on the population.

Until 2018, information on toothfish bycatch in the calamari trawl fishery came from fishery self-reporting (compulsory on all vessels, but likely inaccurate because the commercial fishery has little incentive to accurately report bycatch, in addition to juvenile toothfish being difficult to distinguish from other small fish), and from FIFD observers (likely more accurate, but with limited coverage). Regarding the regulation in this period, allowable toothfish bycatch per vessel-day was limited to 10% of the total catch weight, the same as any other non-target species; exceeding this threshold would trigger a move-on rule, forcing the vessel to leave the grid square for ten days. However, due to the small size of toothfish captured in trawl fisheries (calamari fishery especially), their catch weight is often minimal and makes up a (very) low percentage of the total catch; consequently, the 10%-threshold move-on rule in the calamari trawl fishery appears to have never been triggered.

Starting with 2018, two major changes occurred in the calamari trawl fishery: i) the observer coverage was strongly increased because of the presence of marine mammals (full coverage by contract observers), the side-effect being a more extensive reporting on juvenile toothfish bycatch, and ii) move-on rule threshold for toothfish bycatch has been changed from 10% to 1.5%. The second change was a direct response to the trend of increasing finfish fishery effort in deeper waters during 2016-2017 which, combined with the progression of high recruitment 2015 cohort into deeper waters, resulted in record toothfish bycatch, but even then, the 10% bycatch was rarely exceeded due to the significant catches of target species (Randhawa 2020).

The objective of the current report was to synthesize all data we have available on juvenile toothfish bycatch in the calamari trawl fishery and create an overview of: i) how toothfish bycatch trends changed inter-annually during the most recent 10-year period, ii) how toothfish bycatch reporting practices (FIFD observers, contract observers, fishery self-reporting) evolved during this time, and iii) how 1.5% move-on rule threshold affected toothfish bycatch in the calamari fishery. Finally, recommendations are made on potential improvements to the toothfish bycatch reporting practice, data management, and fishery management measures.

2. Material and Methods

2.1. Data

Several datasets pertaining to the calamari trawl fishery were used in the analysis (Table 1) and are detailed below.

The daily catch dataset covered the longest time period (2012-2021) and provided insight into the historical toothfish bycatch trends, as reported by the fishery. However, these data are reported per day and it is not straightforward to compare them with the data reported per haul by the fishery observers; the problem is that not all hauls are observed, so pooling toothfish bycatch for all observed hauls on a given day does not necessarily match the daily toothfish bycatch reported by the vessel (additional toothfish might have been caught during the unobserved hauls).

The e-logbook dataset provided the desired resolution of the fishery self-reporting (per haul) but only the data for the second half of the considered period (2017-2021) were of sufficient quality. Earlier data were sparse/incomplete due to some vessels not submitting their e-logbooks to FIFD (Alex Blake, pers. comm). Still, the available data could be directly compared with the observer data, providing valuable information on potential over- or under-reporting by the fishery.

FIFD observer data provided reliable long-term (2012-2021) per-day data and short-term (2017-2021) per-haul data, but overall coverage of the fishery was low (on average <10% of annual effort). Contract observer data provided somewhat less reliable (as not primarily tasked with fish sampling) short-term (2018-2021) per-haul data, but had almost full coverage[1] of the fishery. Both FIFD and contract observer datasets were compared with e-logbook data where they overlapped (2017-2021 and 2018-2021, respectively). Additionally, FIFD observer data for the earlier period (2012-2016) were qualitatively compared to daily catch reports; as mentioned above, direct bycatch weight comparison was not possible, but a limited comparison of the frequency of toothfish reporting was provided.

Data on toothfish size-structure in the calamari trawl fishery, collected by FIFD observers, were compiled over the longest period considered in the analysis (2012-2021) and used to provide context to the observed bycatch trends (e.g. contribution of different cohorts to the bycatch). Size-structure was created by raising the observed length frequencies in each haul to the total catch, and then pooling them over seasons as required. Toothfish size structure reported during the calamari pre-recruitment surveys, and a single juvenile toothfish survey, was also included in the analysis; although not belonging to the commercial fishery, these data pertain to the same area/period and provide valuable information on toothfish cohorts' progression through the fishery.

Table 1. Description of datasets used in the analysis.

	Daily catch data	**e-logbook data**	**FIFD observer data**	**Contract observer data**	**FIFD observer / research survey data**
Provided by:	Fishery self-reporting	Fishery self-reporting	FIFD fishery observers during commercial fishing trips	Contract marine mammal observers during commercial fishing trips	FIFD fishery observers during both commercial trips and research surveys
Available in:	FIFD catch database	FIFD catch database	FIFD observer database	Contract observer raw data (Excel files)	FIFD observer database

[1] Full coverage in terms of every vessel having an observer onboard; not monitoring every haul.

Resolution:	per-day	per-haul	per-haul	per-haul	per-haul
Time-series:	2012-2021 (earlier data considered unreliable due to infrequent toothfish reporting)	2017-2021 (earlier e-logbook data sparse / incomplete)	2017-2021 (selected to match e-logbook data)	2018-2021 (Contract observer programme started in 2018)	2012-2021 (selected to encompas other data-sets)
Relevant info:	toothfish catch, total catch, report id, vessel id, date, position (by grid square), licence used, effort (vessel-days and hours)	toothfish catch, total catch, haul id, vessel id, date, position (Lon, Lat), licence used, and effort (hours)	toothfish catch, total catch, haul id, vessel id, date, position (Lon, Lat), licence used, and effort (hours)	toothfish catch, total catch, haul id, vessel id, date, position (Lon, Lat), licence used, and effort (hours	toothfish catch, toothfish length distribution, haul id, vessel id, date

2.2. Move-on rule analysis

To inform the systematic selection of the potential new move-on rule thresholds in the calamari trawl fishery, toothfish cumulative bycatch-per-haul curves were examined to distinguish between the initial part of the curve associated with a linear increase and the final part of the curve associated with an asymptotic plateau in the slope (Figure 1). Assuming a relationship between the toothfish bycatch-per-haul and abundance, the transition between these two parts of the curve, especially if sharp, could potentially indicate a naturally occurring reference point; e.g., a large bycatch would correspond to the hotspot of the toothfish abundance and would be on the right asymptotic side of the cumulative curve. The following three methods have been adopted from Geange *et al.* (2020) to calculate the potential reference points (Figure 2):

1) the position of the final breakpoint of a three-parameter segmented regression fitted to the data using the R package *'segmented'* (Muggeo 2008);
2) the point on the cumulative distribution that is closest to the top-left corner (0,1); and
3) the point on the cumulative distribution that maximizes the distance between the curve and a line drawn between the extreme points on the curve (Youden Index).

Segmented regressions are commonly used to identify breakpoints which differentiate data into different groups based on changes in the relationship between dependent and independent variables (Ochoa-Quintero *et al.* 2015; Robertson *et al.* 2016). Points on a curve closest to (0,1) or which maximize Youden Index are commonly used in medical research to identify thresholds and facilitate treatment decisions (Youden 1950; Tilbury *et al.* 2000). The details on the calculation of all three reference points are available in Geange *et al.* (2020).

The catches corresponding to the reference points calculated by the three methods were explored as potential move-on thresholds.

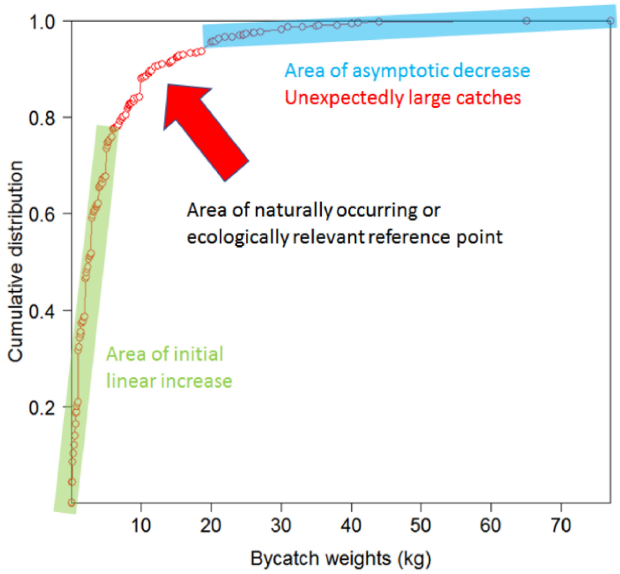

Figure 1. Generic cumulative distribution curve of toothfish bycatch-per-haul, where the initial part of the curve associated with linear increase is distinguished from the final part of the curve associated with asymptotic decrease. The area distinguishing between these two parts of the curve potentially indicates a naturally occurring or ecologically relevant reference point (Geange *et al.* 2020).

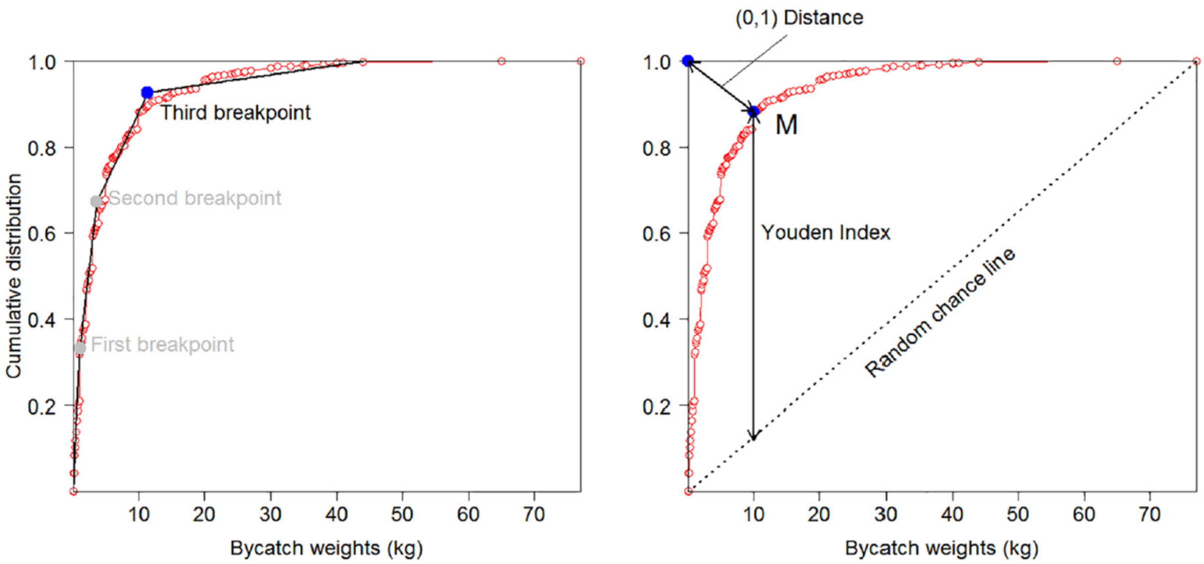

Figure 2. Generic cumulative distribution curve and three approaches used to distinguish between the initial part of the curve associated with linear increase and the final part of the curve associated with asymptotic decrease: (1) the third breakpoint in a 3-parameter segmented regression (left-hand panel); (2) the point on the curve that is closest to the top-left corner [(0,1) Distance, right-hand panel]; and (3) the point on the curve that maximizes the distance between the curve and a random chance line drawn between the extreme points on the curve (Youden Index, right hand panel) (Geange *et al.* 2020).

3. Results and Discussion

Chapter 3.1 provides an overview of toothfish bycatch as reported by the fishery (per-day reports since 2012, and per-haul reports since 2017). Chapter 3.2 provides the size-structure of toothfish bycatch, and toothfish cohorts' progression through the fishery over the last 20 seasons (2012-2021, two seasons per year). Chapter 3.3 provides a comparison of the reported and observed toothfish bycatch; data is split into FIFD observer data (low-intensity but long-term coverage) and contract observer data (high-intensity but short-term coverage). Chapter 3.4 analyses the effects of a move-on rule on toothfish bycatch and fishing practice in the calamari trawl fishery.

3.1. Toothfish bycatch overview

In the Falkland Islands, calamari trawl fishery operates two fishing seasons per year: the first takes place in March-April under the C-Licence, and the second in August-September under the X-Licence. Throughout the report, the first season is also referred to as 'C' season, and the second as 'X' season, sometimes in combination with a year (year-season, e.g. 2018_C and 2018_X).

Over the last 10 years (20 seasons), the total toothfish bycatch in the calamari trawl fishery ranged between 0.5 and 52.2 tonnes per year. The highest bycatch occurred in 2016, predominantly during the second season. Following the 2016 peak, in 2017 the bycatch approximately halved to 25.1 t, and in all other years remained below 10.0 t (Figure 3.A). As the targeted calamari catch in the same period ranged between 29.6 - 94.2 thousand tonnes, and the total catch between 43.3 - 96.0 thousand tonnes, toothfish bycatch corresponded to a negligible proportion of the overall catch. For example, in 2016, the year of the highest absolute toothfish bycatch, toothfish comprised only 0.1% of the total annual catch (Figure 3.B; note that the bycatch proportion is disaggregated by season in the figure).

In most years, toothfish bycatch (both absolute and relative) was higher during the second season compared to the first season, most likely due to the individual fish growth over the intervening 6 months. A detailed structure of toothfish bycatch, i.e. the contribution of different cohorts to the total bycatch, is explored in chapter 3.2.

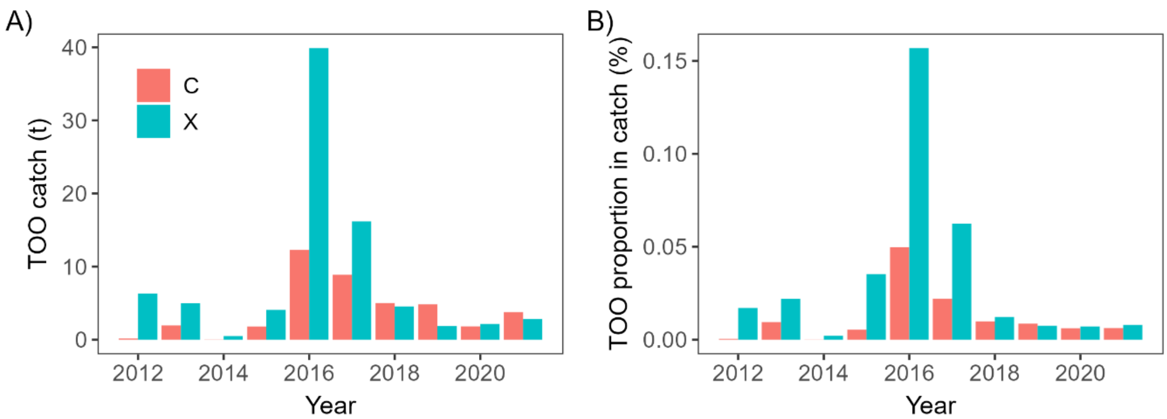

Figure 3. Absolute (A) and relative (B) toothfish bycatch in the calamari trawl fishery over the last 10 years (20 seasons). C and X stand for first and second season, respectively.

The spatial distribution of toothfish bycatch per grid-square is given in Figure 4; the two years with the highest recorded bycatch (2016 and 2017) show a concentration of bycatch in the south of the Loligo Box during the first season and a more dispersed bycatch throughout the Box during the second season. This was less obvious in other years, possibly due to a low overall bycatch. In general, toothfish bycatch was more associated with the south sub-area of the Loligo Box (south of 52°S).

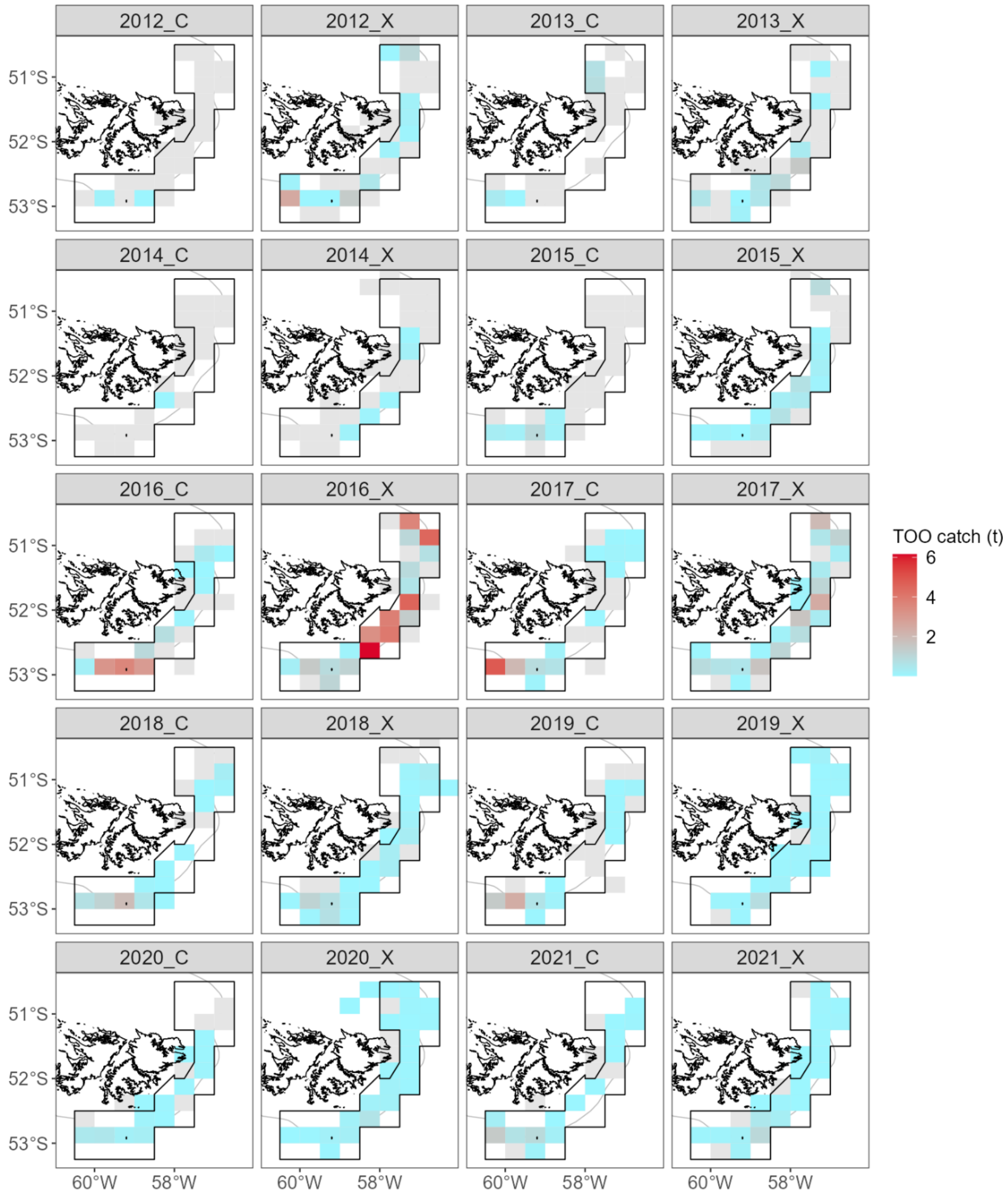

Figure 4. Spatial distribution of toothfish bycatch in the calamari trawl fishery, per year-season. Toothfish catch was reported per vessel-day (i.e. pooled over all hauls by a given vessel on a given day) and the position was reported per grid-square (i.e. location of the vessel at mid-day). Grey shading denotes grid-squares fished but with zero reported toothfish bycatch.

The resolution of spatial data presented in Figure 4 is low, as catches were aggregated per vessel-day, and positions were reported per grid square (position of the vessel at mid-day). High-resolution data was obtained from e-logbooks, where the catch and position are reported per haul; the drawback being a shorter time-series, with complete annual data available only from 2017. This means that the year with the highest bycatch (2016) had to be omitted, but the year 2017 showed a clear concentration of the bycatch in south-eastern range of effort distribution during the first season, and a more dispersed bycatch throughout the Loligo Box during the second season (Figure 5). The remaining years had a very low bycatch and trends were not as obvious, but it does appear that higher than average bycatch commonly occurred in the south-western range of effort distribution.

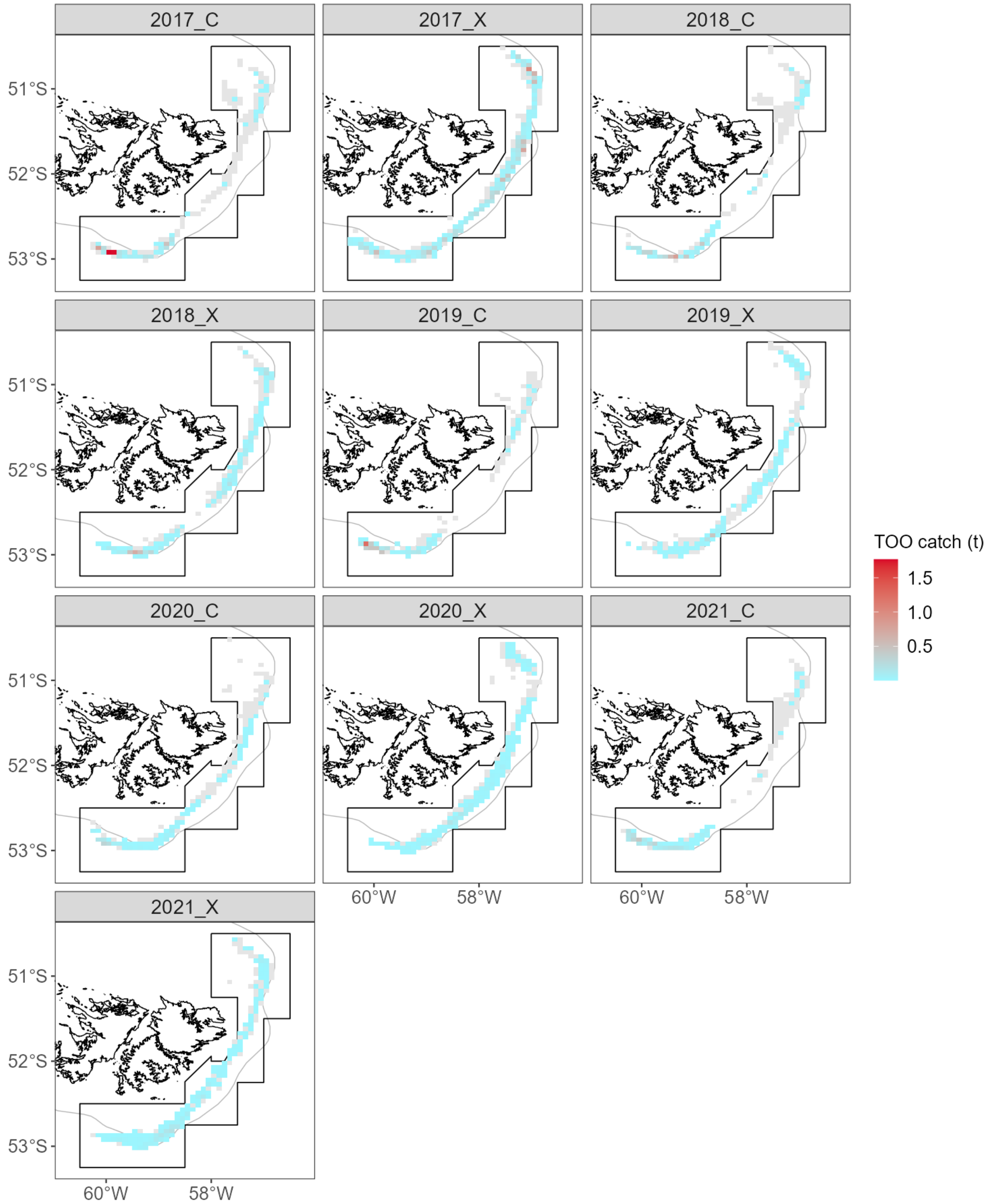

Figure 5. Spatial distribution of toothfish bycatch in the calamari trawl fishery, per year-season. Toothfish catch and position were reported per haul; data were post-hoc aggregated at fine spatial resolution (0.1° Lon * 0.05° Lat) to aid visual interpretation. Grey shading denotes areas with zero reported toothfish bycatch.

3.2. Toothfish bycatch size-structure

Size-structure (length) of toothfish bycatch in the calamari trawl fishery and corresponding research surveys is given in Figure 6. All the data were collected by FIFD fishery observers during the commercial fishing trips, prerecruitment surveys, and a single 'juvenile toothfish' survey (Arkhipkin *et al.* 2017).

Although Figure 6 does not include age structure explicitly, the progression of age-structured cohorts can be discerned from the seasonal size-structure distributions. In general, cohort progressions were relatively well defined over the first 5-8 seasons (Figure 6, solid lines), after which point fish leave the area for deeper waters (ontogenetic migration). Cohorts were especially well defined for fish hatched in 2014 and 2016, and first detected in survey catches half a year later, at the onset of seasons 2015_C and 2017_C (Figure 6, green and red lines); both were high recruitment cohorts (Lee *et al.* 2021). Note that the histogram heights in Figure 6 are relative for each year-season and cannot be used to directly discern the individual cohort strength; for the cohort strength, we relied on the findings of Lee *et al.* (2021). Fish hatched in 2014 were first detected during the prerecruitment survey in 2015_C, and fish hatched in 2016 during the one-time 'juvenile toothfish' survey in 2017_C; it appears that the latter were also found in high quantities during the prerecruitment survey in 2017_C (Brendon Lee, FIFD, pers. comm.), but were not recorded in the database and are thus not reflected in the figure. These samples were possibly allocated for a specific project, and data might have been recorded elsewhere (Brendon Lee, FIFD, pers. comm.). The fact that strong cohorts entering the Loligo Box can be detected very early in their life history (via a high proportion of ~0.5 years old fish), during the C-season prerecruitment surveys, could prove useful in informing management; it is an early warning of the potential bycatch issues in the following commercial season(s).

A comparison of cohort progressions (Figure 6) with toothfish bycatch in the commercial fishery (Figure 3.A) suggests that strong cohorts don't contribute to high bycatch rates immediately after they enter the fishery, likely due to the small individual fish size. For example, the strongest cohort of the last ten years first entered the fishery in 2015_C, but this turned out to be one of the seasons with the lowest bycatch on record. However, due to individual growth, fish from this cohort supported an almost 10-fold increase in bycatch by 2016_X; this was the season with the highest recorded bycatch, consisting almost entirely of 2-year-old fish from the 2015 cohort (Figure 6, panels 2015_C to 2016_X). In 2017_C another strong cohort entered the fishery (although weaker than the 2015 cohort) with both cohorts contributing to the bycatch up to season 2019_C (older fish from cohort 2015 and younger fish from cohort 2017). By 2020, fish from these two strong cohorts (now ~3-4 years old) presumably left the fishery area for deeper waters; at the same time, only weak cohorts entered the fishery in 2018-2021 (Lee *et al.* 2021), resulting in an overall low toothfish bycatch in 2019-2021.

In conclusion, toothfish bycatch in the calamari trawl fishery depends on the presence of strong individual cohorts; the bycatch trend over the last 10 years was predominantly shaped by the progression of the strong 2015 cohort through the fishery area. It should be noted that toothfish bycatch reporting and management is based on weight; however, toothfish enter the fishery already when ~0.5 years old when, due to the small individual size, very large numbers can be captured that amount to comparatively low bycatch weight. This highlights the importance of C-season pre-recruitment surveys in the early detection of strong cohorts (high recruitments) and suggests that care should be taken if attempting to protect the youngest age class via weight-based bycatch management measures. This is discussed in more detail further in the report.

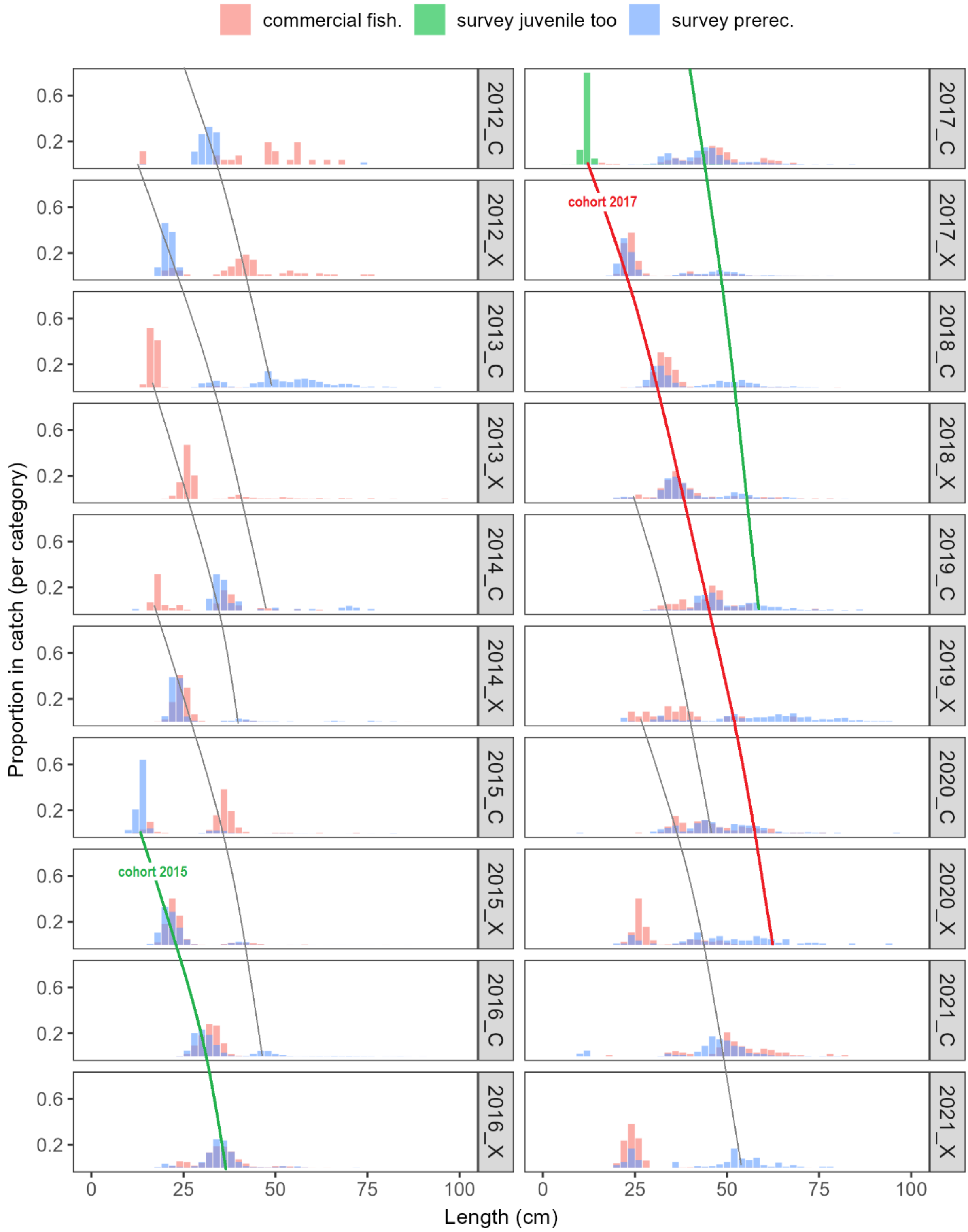

Figure 6. The observed length frequency distributions for toothfish sampled in the Loligo Box during 2012 to 2021. Proportion in catch values are relative for each year-season. Lines reflect progression of cohorts through time; green and red line denote strong cohorts first observed in 2015 and 2017, respectively. Note that lines are suggestive only, aiming to aid visual interpretation.

3.3. Toothfish bycatch monitoring and reporting

Historical trends in observer coverage, toothfish reporting frequency, and toothfish bycatch weight, in the calamari trawl fishery, are given in Figure 7. During the last ten years, fishing effort fluctuated around 937 vessel-days per season and was consistently monitored by FIFD fishery observers, albeit at relatively low coverage (7-10% vessel-days annually, with a single 17% peak in 2017_X). A contract observer programme was introduced in 2018, aiming to achieve full coverage of the fishery but falling short in a few seasons due to technical difficulties (83-100% vessel-days annually; lower coverage in 2018_C was due to travelling arrangement issues, and in 2020_X to 2021_X due to COVID-19 related measures) (Figure 7.A). The time-series in Figure 7 can be broadly divided into three distinct periods, according to levels of bycatch, monitoring and reporting:

- The early period (2012-2015) spanned 8 seasons, characterised by low reported toothfish bycatch weight, infrequent reports of toothfish bycatch, and low observer coverage (Figure 7, up to the first dashed line). Throughout this period, toothfish bycatch was reported on 0-10% vessel-days per season.
- The transition period (2016-2017) spanned 4 seasons, characterised by high reported toothfish bycatch weight, frequent reports of toothfish bycatch, and low observer coverage (Figure 7, between the two dashed lines). Throughout this period, toothfish bycatch was reported on 12-38% vessel-days per season. FIFD observer coverage was increased ad-hoc in 2017_X due to the increased presence of marine mammals but remained low overall.
- The recent period (2018-2021) spanned 8 seasons, characterised by low reported toothfish bycatch weight, frequent reports of toothfish bycatch, and high observer coverage (Figure 7, after the second dashed line). This period saw an almost 10-fold increase in observer coverage due to the introduction of the contract observer programme; although primarily tasked with monitoring marine mammal bycatch, contract observers provided coverage of toothfish bycatch as well. Toothfish bycatch was reported on 18-48% vessel-days per season, but overall bycatch weight remained low due to a prolonged period of low recruitments (as described in Chapter 3.2).

When comparing the early period with the recent period, there is a striking difference in the frequency of toothfish bycatch reports (low → high), even though the reported bycatch weight was comparable between the two. This suggests that the average bycatch weight-per-report used to be much higher, i.e. only large bycatches used to be reported; this is explored in more detail further in the report.

Vessel-disaggregated data on observer coverage and frequency of toothfish reporting is given in Figure 8. In the early period, most vessels reported toothfish infrequently (vessel_17 being a notable exception to the rule, and vessel_5 and vessel_18 also standing out). Some vessels haven't reported any toothfish bycatch throughout this entire period (vessel_2, vessel_8, vessel_15), while others reported it only when they had observer coverage (vessel_3 being the clearest example, but also vessel_11 and vessel_19). Starting with 2016, toothfish bycatch reporting became much more frequent throughout the fleet.

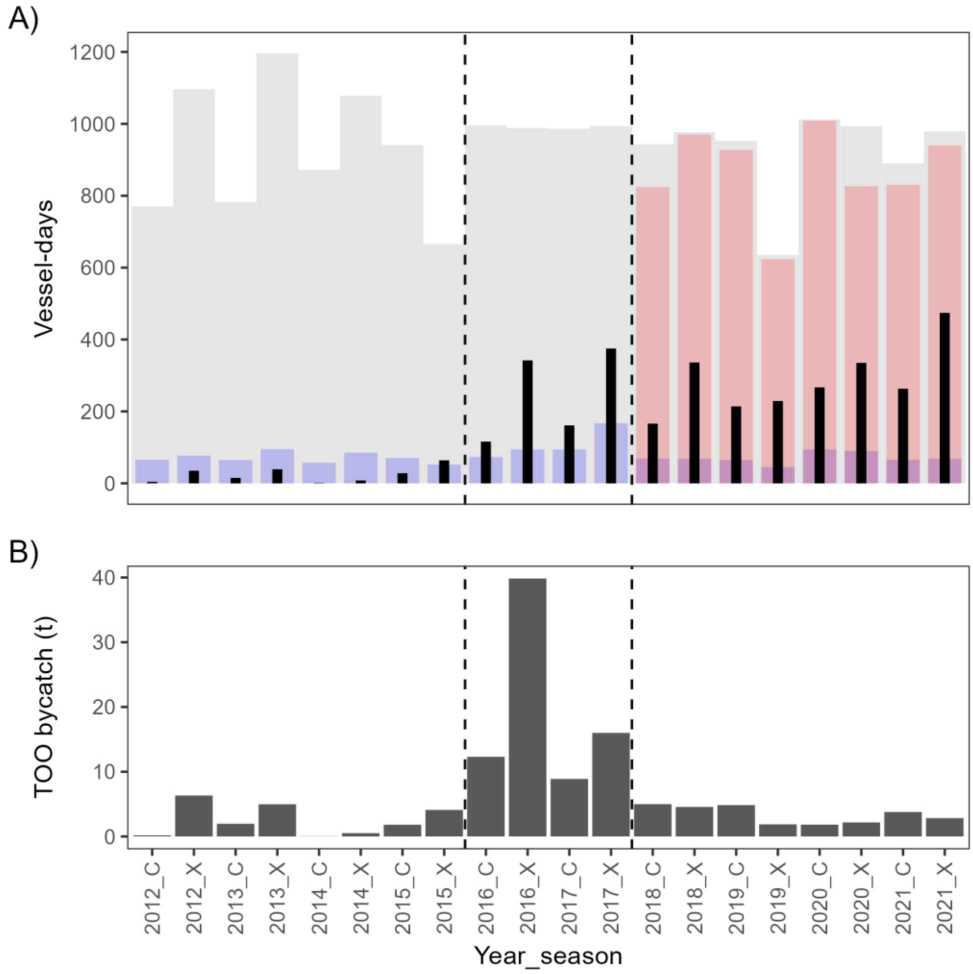

Figure 7. A) Total fishing effort (grey), FIFD observer coverage (blue), contract observer coverage (red) and frequency of toothfish bycatch reports (black) in the calamari trawl fishery during 2012-2021. B) Toothfish bycatch in the calamari trawl fishery during 2012-2021. Dashed lines delineate three distinct time periods described in the text.

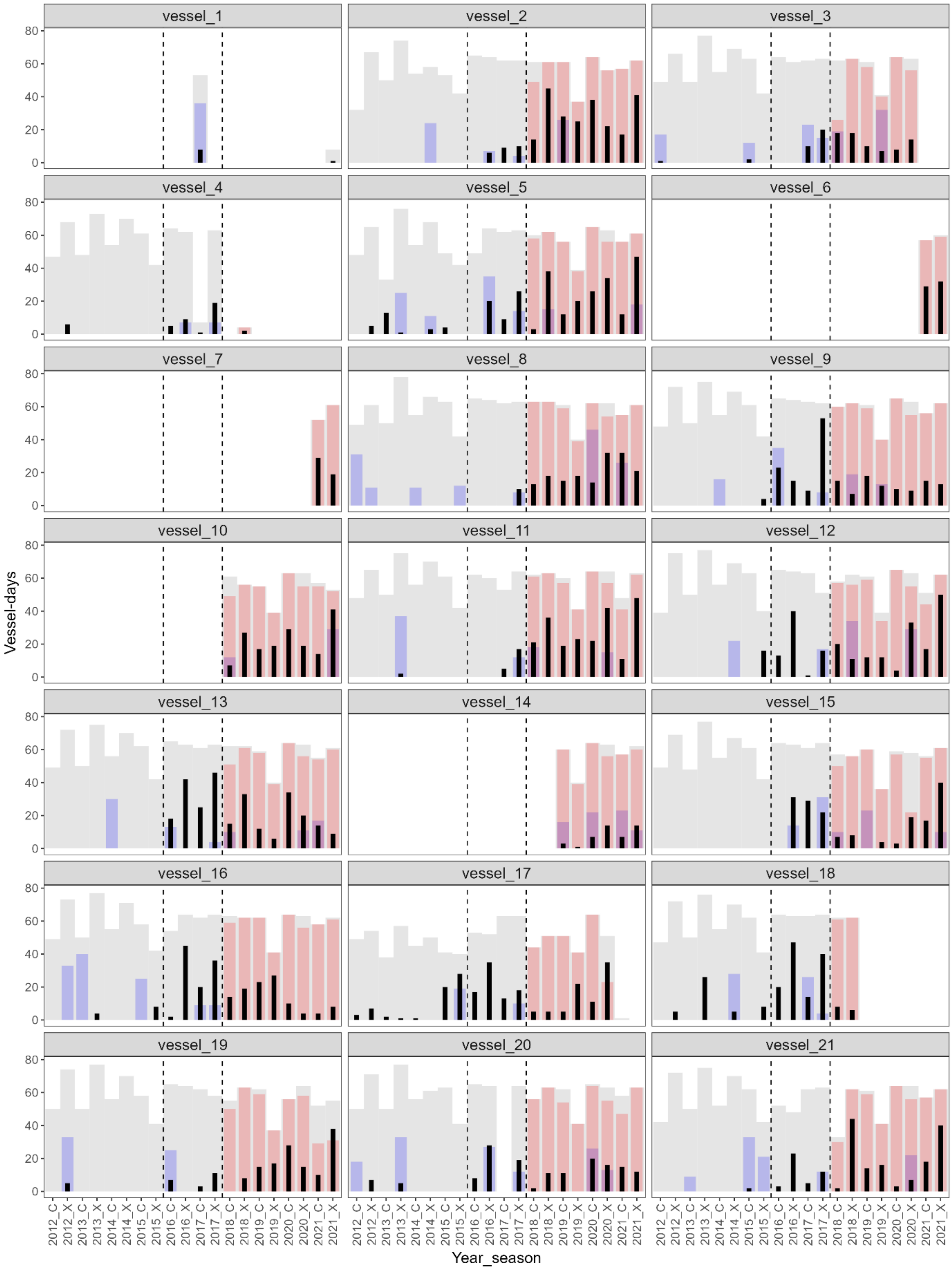

Figure 8. Total fishing effort (grey), FIFD observer coverage (blue), contract observer coverage (red) and frequency of toothfish bycatch reports (black) in the calamari trawl fishery during 2012-2021, per vessel.

Further insight into toothfish bycatch reporting practice was gained by partitioning the frequency of reporting according to bycatch size (Figure 9). The multi-coloured columns correspond to the black lines in Figure 8, i.e. to the number of vessel-days with reported toothfish bycatch; here, these are partitioned between bycatch sizes, ranging from small (<1 kg / vessel-day) to large (>100 kg / vessel-day). Again, we can see a clear difference in reporting between the three periods:

- In the early period (2012-2015), all reported toothfish catches were large (>50 kg / vessel-day). It is unlikely that no small catches were taken during this entire time, so we can assume a level of non-reporting.
- In the transition period (2016-2017) there was a large increase in reporting frequency that can be attributed to two factors: i) due to the presence of two strong cohorts in the fishery area, toothfish was caught more frequently and in higher quantities than before, as reflected in the increased frequency of large catches (>50 kg / vessel-day), and ii) FIFD increased the effort to correctly identify and report toothfish bycatch (observers were asked to place extra attention towards toothfish bycatch and communicate this with the factory manager and captains), as reflected in the increased frequency of reporting small catches (<50 kg / per vessel-day).
- In the recent period (2018-2021), the frequency of reporting further increased due to the numerous small catches (for the first time, catches of <1 kg / vessel-day were being reported). However, due to a prolonged period of low recruitment, large catches were rare.

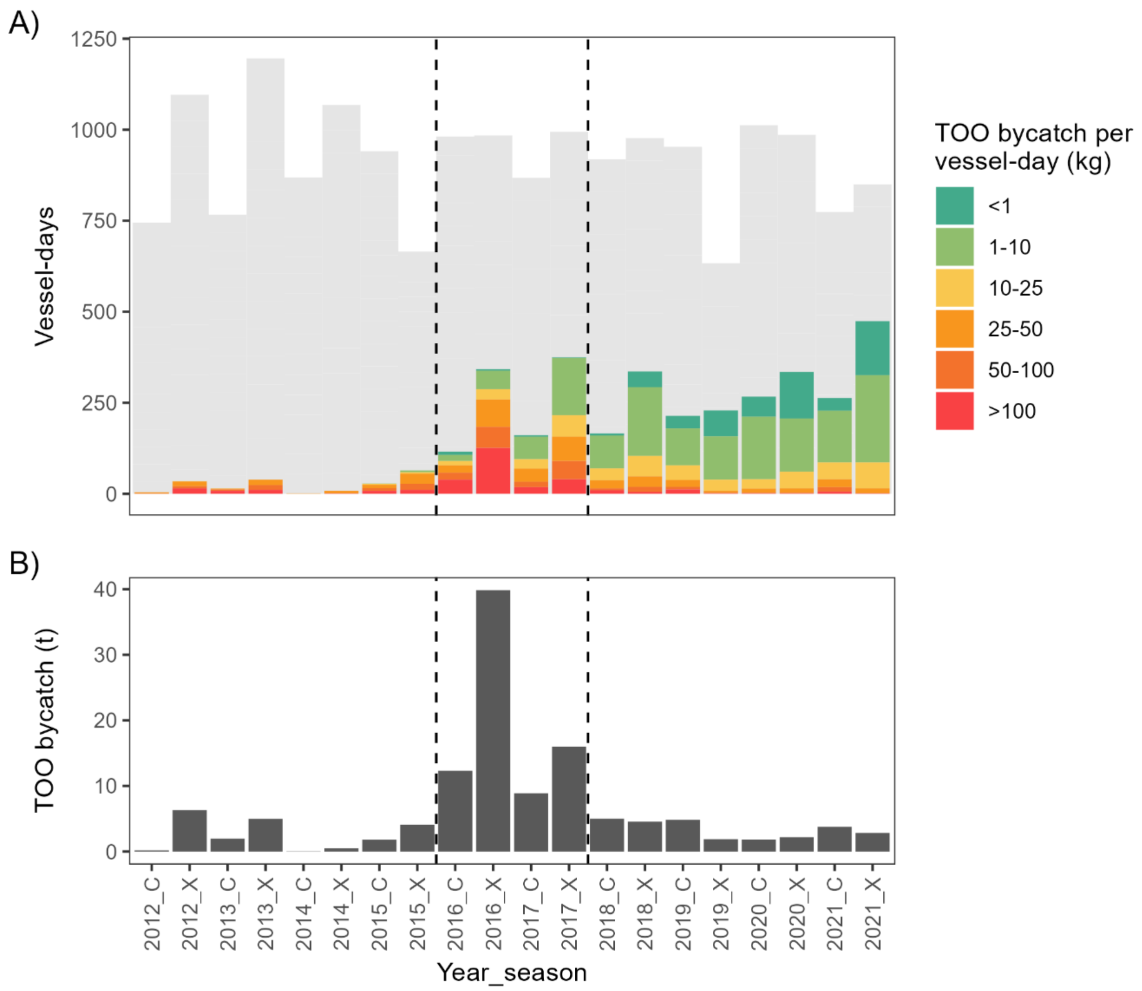

Figure 9. A) Total fishing effort (grey) and the frequency of toothfish bycatch reports in the calamari trawl fishery during 2012-2021, partitioned by bycatch weight (multi-coloured bars). B) Toothfish bycatch in the calamari trawl fishery during 2012-2021. Dashed lines delineate three distinct time periods described in the text.

Vessel-disaggregated data confirmed that the reporting practice progressed along a similar trend across the fleet (Figure 10). No vessels reported small toothfish catches in the early period, and all vessels had frequent reports of even the smallest catches in the recent period.

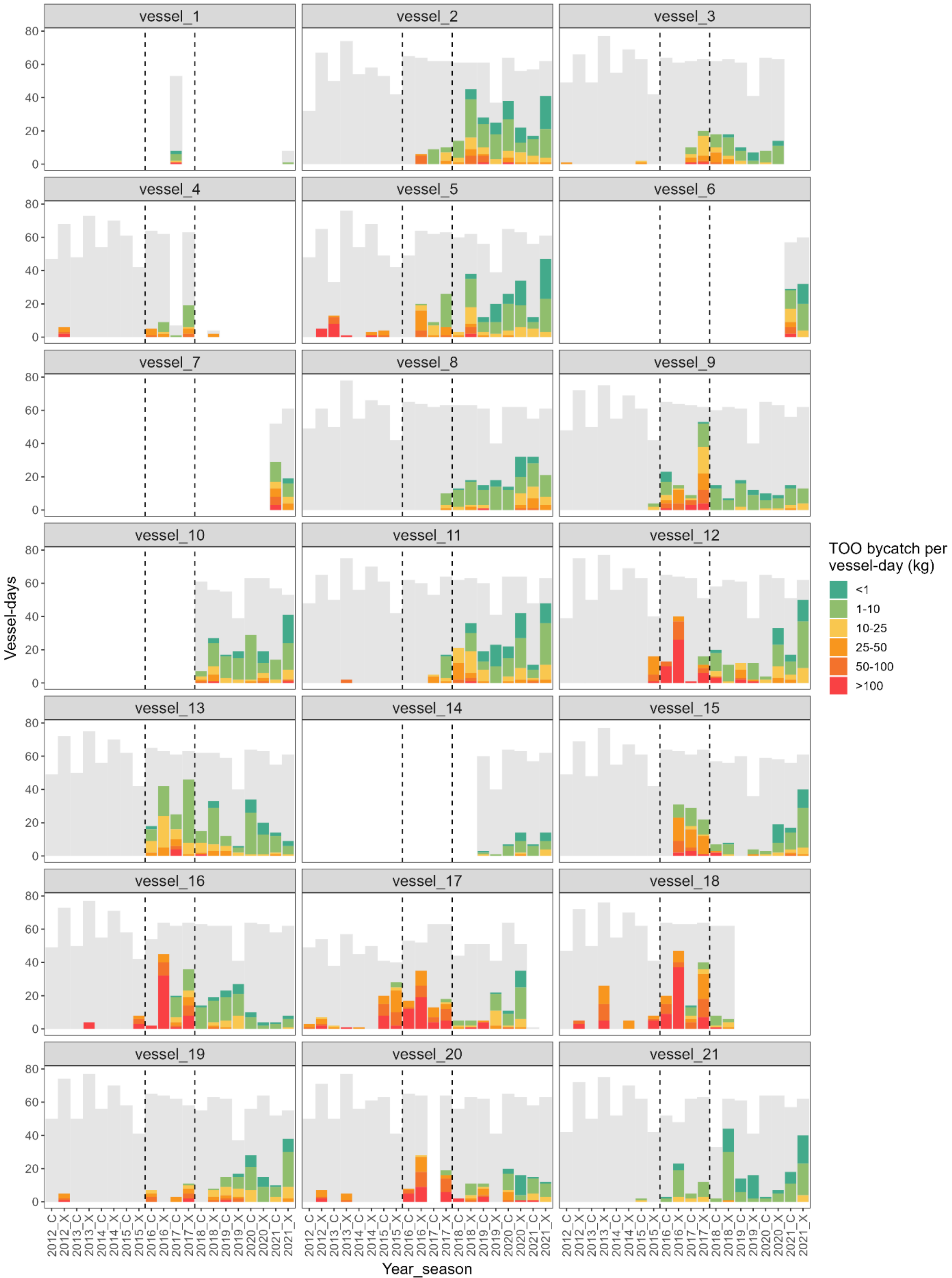

Figure 10. Total fishing effort (grey) and the frequency of toothfish bycatch reports partitioned by bycatch weight (multi-coloured bars), per vessel.

Overall, the analysis showed a clear evolution of toothfish bycatch reporting practice in the calamari trawl fishery; from low monitoring and infrequent reporting (only large catches) in the early period, through increased catches, monitoring and reporting during the transition period, to intensive monitoring and frequent reporting (even the smallest catches) in the recent period.

However, this analysis didn't test the plausibility of the reported data. For example, we can presume a level of non-reporting in the early period because it would be difficult to explain the lack of small bycatches otherwise, but the only way to prove it is by comparing the self-reported data with the observer data. As explained in Methods, it is not straightforward to compare observer data collected per haul with the self-reports aggregated per day; therefore, in the following chapters, the observer data were compared with the available e-logbook data, as both are reported per haul.

3.3.1. Self-reported vs. FIFD observer data

Fishery e-logbook (self-reported) data were compared with FIFD observer data over the period 2017-2021; the earlier e-logbook data were incomplete. Matching observed data to e-logbook data was not straightforward because, by design, the observer and vessel assign non-matching IDs to the same haul. Therefore, corresponding hauls had to be matched based on callsign (to match the vessel), date (to match the day) and time of day (to match the individual haul). Matching the time-of-day proved difficult in many cases, as the observer and vessel would report different times; these discrepancies were a mix of systematic errors (different time zones applied by the vessel and the observer, usually resulting in an exactly ±1-hour offset), and 'random' errors (independent time-readings taken by the vessel and the observer, rarely resulting in an exact match required by the matching algorithm). Out of 4,728 observed hauls, only 70.9% had an exact time-of-day match in the e-logbook; 7.6% were off by exactly ±1-hour, 2.8% were off within ±1-hour, and 18.7% haven't been matched to any e-logbook haul. This issue should be revisited in the future, perhaps by having observers report haul IDs assigned by the vessel, in addition to their own 'station' IDs. This would make data matching trivial, in contrast to the current practice, which is time-consuming, coding intensive, and only partially successful.

The following analysis was conducted on successfully matched hauls only. When comparing observed data and e-logbook data, observed data were assumed correct and e-logbook data were assessed against it (e.g. under-reporting would mean that e-logbook catch < observed catch.). It was necessary to consider either reported or observed data as 'true', otherwise it would be impossible to distinguish between vessel over-reporting and observer under-reporting, and vice versa. Considering observed data as 'true' seemed reasonable, although, in case of large discrepancies, a more detailed examination was conducted.

The relationship between FIFD-observed and e-logbook toothfish bycatch per haul is given in Figure 11. Each haul is represented by a red point; ideally, all points would lie on 1:1 dashed blue lines, indicating an exact match between the reported and observed catch. The spread around the blue line was quite large in some seasons, suggesting erroneous reporting[2]; however, this is not as clear as it appears. The problem is that some vessels don't report exact toothfish bycatch taken per haul; instead, toothfish bycatch is collected until it fills a 'box', which can take multiple hauls. The entire toothfish bycatch in the box is reported to belong to the haul in which the box was filled (Toni Trevizan, FIFD, pers. comm.). This can lead to the vessel under-reporting toothfish on two hauls (because observers are reporting correctly, while the vessel reports zero) and over-reporting on the third haul (because observers report bycatch taken on the third haul, while the vessel reports pooled bycatch of all three hauls). A further complication arises from the fact that the vessel might collect bycatch during the unobserved haul and assign it to the observed haul once the box is filled, leading to over-reporting. All this needs to be considered when comparing observed and reported bycatch; any borderline

[2] For this report, 'erroneous reporting' was defined as any discrepancy between observed (=true) and reported bycatch, regardless of the cause.

differences will likely have to be ignored. The first step in resolving this issue could be instructing vessels to report toothfish bycatch per haul, without exception.

To overcome the above-mentioned inaccuracies, and explore trends underlying individual reports, linear models were fit to each season's data (Figure 11, red lines). There was an indication of under-reporting in 2017_X and over-reporting in 2019_C; the discrepancy between linear models and the 1:1 line appeared minor in all other seasons.

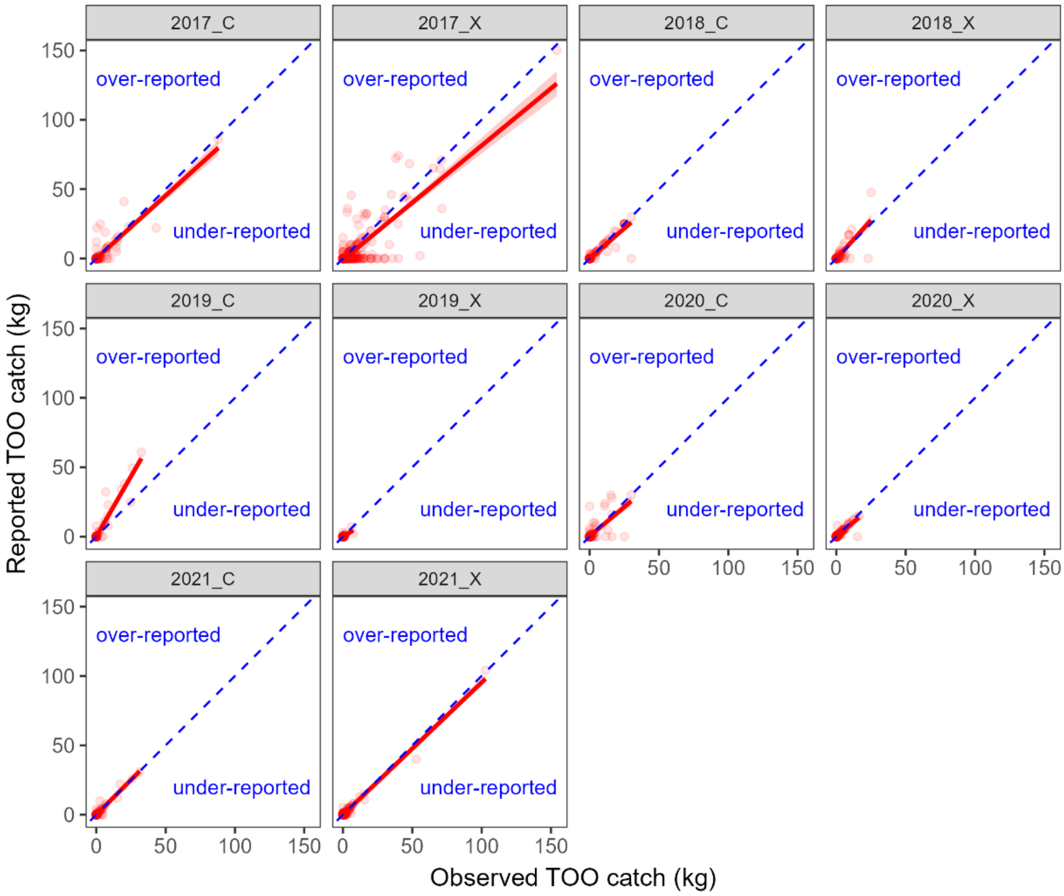

Figure 11. FIFD-observed vs. e-logbook toothfish bycatch per haul (red points) in the calamari trawl fishery during 2017-2021. Linear models (red lines with 95% CI) were fitted to facilitate comparison against 'reported = observed' lines (dashed blue lines).

To estimate the magnitude of erroneous reporting, the absolute and relative differences between the total observed and reported toothfish bycatch per season were explored (Figure 12). Due to low toothfish bycatch in certain seasons, high relative discrepancies can arise from very low absolute catches; good examples are 2019_X, where an under-reporting of 27% was calculated from the reported catch of 20 kg and observed catch of 27.5 kg, and 2019_C, where over-reporting of 80% was calculated from the reported catch of 324 kg and observed catch of 180 kg. Also, high within-season variability in erroneous reporting was observed (between individual hauls). To account for this, individual hauls in each season were bootstrapped (resampled with replacement) and the relative difference between observed and reported toothfish bycatch was recalculated; this was repeated 1000 times and used to create 95% confidence intervals of the empirical values. Statistically significant differences were found in 2017_X (under-reporting) and 2019_C (over-reporting) (red dots and lines in Figure 12.B).

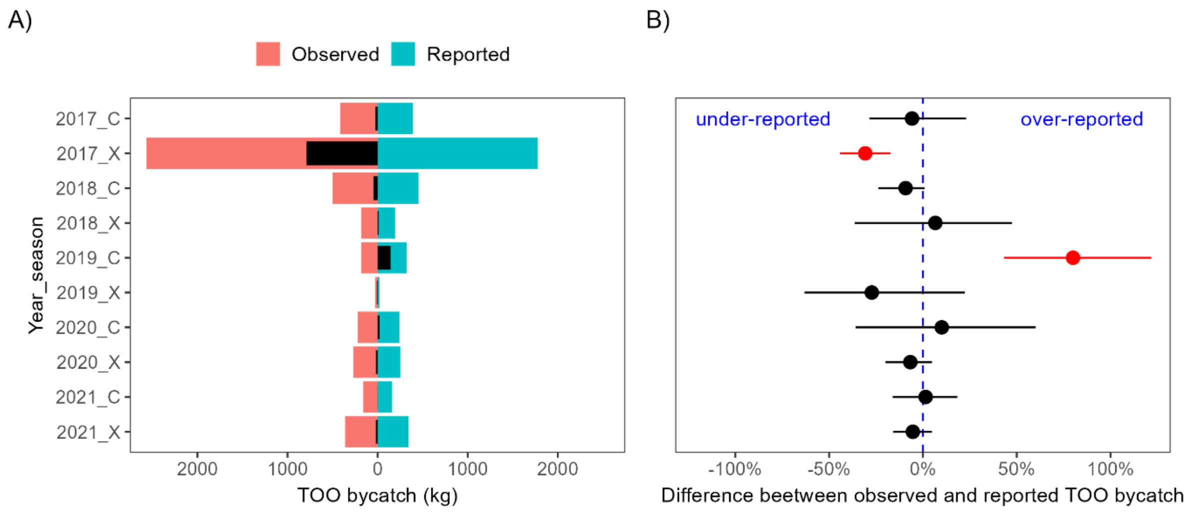

Figure 12. A) Total observed and reported toothfish bycatch in the calamari trawl fishery during 2017-2021, with absolute differences between the two denoted by black lines. B) Relative differences between observed and reported toothfish bycatch, calculated as (reported - observed) / observed; dots are empirical (observed) values, and horizontal lines are bootstrapped 95% CI.

Vessel-disaggregated differences between FIFD-observed and e-logbook-reported toothfish bycatch per season are given in Figure 13. It shows that under-reporting in 2017_X was common throughout the fleet (this season was unique in that it had extensive FIFD observer coverage over 15 vessels, compared to the usual 3-5 vessels). In contrast, over-reporting in 2019_C comes from a single vessel. A detailed examination of over-reporting by vessel_2 in 2019_C revealed that over-reporting was likely due to the erroneous use of toothfish conversion factor (CF) by the bridge; the common procedure on the vessels is for the factory manager to provide the bridge with the product weights, and for the bridge to multiply these values with pre-defined CFs to arrive at green weight of the catch (Toni Trevizan, FIFD, pers. comm.). However, toothfish in the calamari trawl fishery is seldom processed, but is sometimes kept for consumption on board (code GAL for 'galley' in e-logbook); these fish are supposed to be reported to the bridge as green weight, and CF needs not to be applied. During the initial period of e-logbook use, the reporting practice was not yet uniform over all vessels; it is possible that the observer and factory manager would record green weight (often this information would be shared), the factory manager would forward it to the bridge, but the bridge would occasionally treat it as product weight and apply CF, before reporting to FIFD. This would lead to the reported toothfish bycatch being higher than the observed bycatch, by the value of CF (for toothfish in trawl fishery this value is 1.9). In time, all vessels were instructed that the factory manager is supposed to provide green weight to the bridge if toothfish is designated for consumption on board, and the bridge should report it as such without applying CF (Alex Blake, FIFD, pers. comm.). Even though this might seem trivial, analysis of more extensive contract observer data showed that this problem occurred over multiple vessels and seasons, up to 2020_C; this is explored in more detail in the following chapter.

In conclusion, FIFD observer data suggest that toothfish bycatch was under-reported by 31% (95%CI = 19-44%) in 2017_X. The uncommonly high FIFD observer coverage in this season, coupled with the fact that under-reporting was observed over multiple vessels, provide an additional measure of reliability to this finding. Over-reporting in 2019_C was likely an artefact of the erroneous use of CF, highlighting the importance of a uniform, clearly communicated, reporting practice.

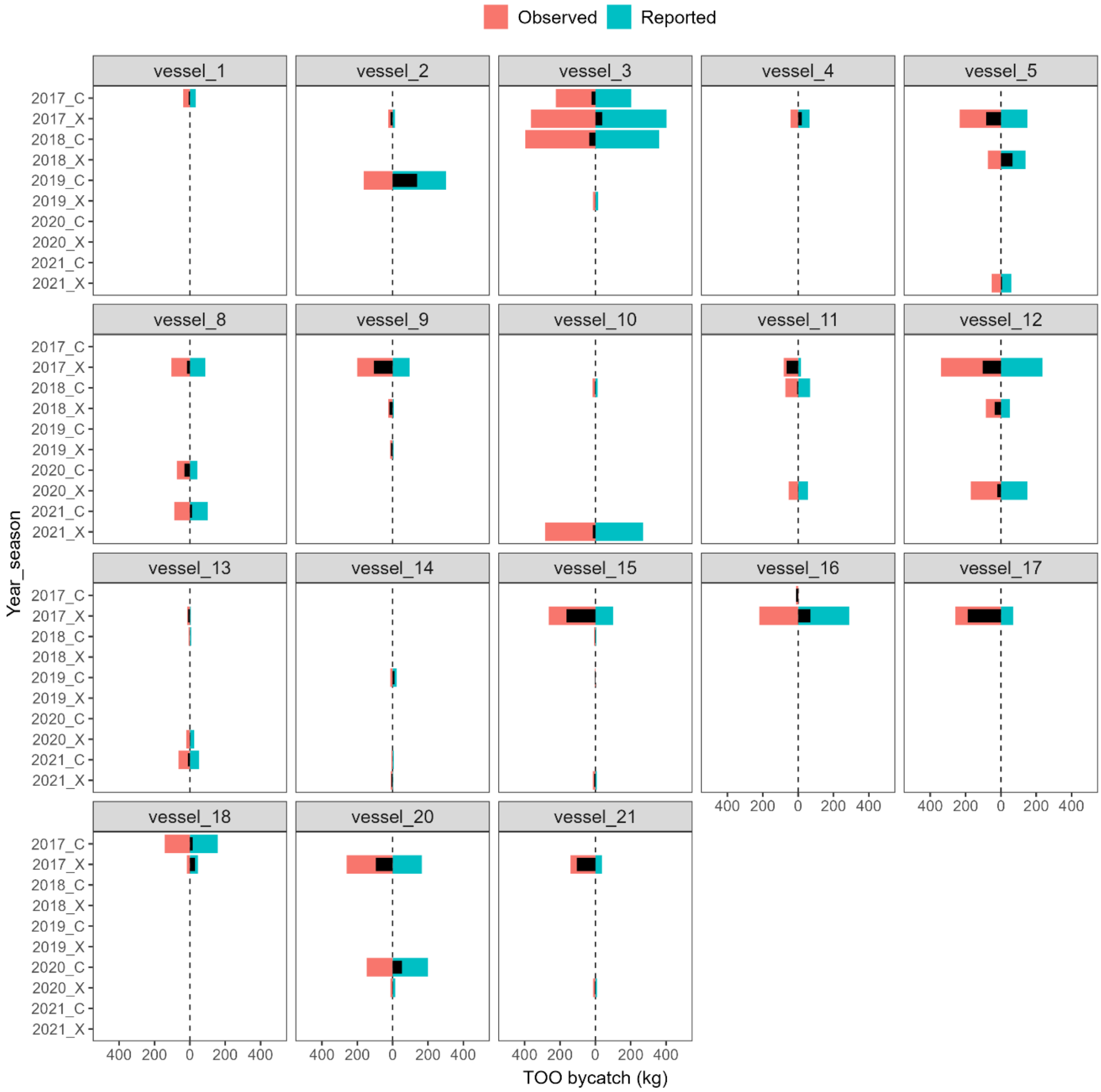

Figure 13. Total observed and reported toothfish bycatch in the calamari trawl fishery during 2017-2021, per vessel, with absolute differences between the two denoted by black lines.

Disaggregating e-logbook data per vessel aimed to look for common patterns; drawing conclusions on systematic over- or under-reporting by individual vessels should be avoided based on FIFD observer data alone. Most of the vessels were observed by FIFD in only 2-3 year-seasons, making it difficult to disentangle vessel and year-season effects. Besides year-season and vessel, individual observers could also be a factor in over- or under-reporting; some observers might share toothfish bycatch estimates with the vessel (leading to an exact match, baring rounding error), while others may not. The observer manual does not strictly define whether observers are to share bycatch information with the vessels they are on, so the practice was probably not uniform across year-seasons and individual observers; it is recommended for this to be discussed at FIFD, and the operational policy explicitly defined. However, the individual observer effect is confounded by both year-season and vessel effects, and given the sparsity of the data (most observers participated in only 1-2 out of the last 10 seasons, and usually visited a single vessel per season) this analysis was not further pursued.

3.3.2. Self-reported vs. contract observer data

Fishery e-logbook (self-reported) data were compared with contract observer data over the period 2018-2021; this covers the duration of the contract observer programme. Contract observer data were available in the form of original excel documents submitted by observers (i.e. ~16 documents per season, each with 8-10 sheets of data). At the time of writing, data needed thorough error-proofing and better integration; the database should be established as soon as possible to facilitate future analyses.

Once extracted and formatted, contract observer data were matched to e-logbook data; the same issue as described for FIFD observed data was encountered, i.e. observers and vessels assign non-matching IDs to the same haul. The method used to match the data, as well as a recommendation on how to avoid this issue in the future, is the same as outlined for FIFD-observed data and is not repeated here. Out of 20,446 observed hauls, 78.7% had an exact time-of-day match in the e-logbook; 15.9% were off by exactly ±1-hour, 4.6% were off within ±1-hour, and 0.8% haven't been matched to any e-logbook haul. The following analysis was conducted on successfully matched hauls.

The relationship between contract observer and e-logbook toothfish bycatch per haul is given in Figure 14. No under-reporting was observed in any season, but there appeared to be a notable over-reporting in 2018_C and 2019_C, as well as a lower level of over-reporting in 2018_X and 2019_X. Note that any borderline differences should be carefully interpreted due to the 'noise' in the data introduced by some vessels reporting pooled bycatch over multiple hauls (the issue with this practice, as well as recommendation on how to resolve it, are the same as outlined for FIFD-observed data and are not repeated here).

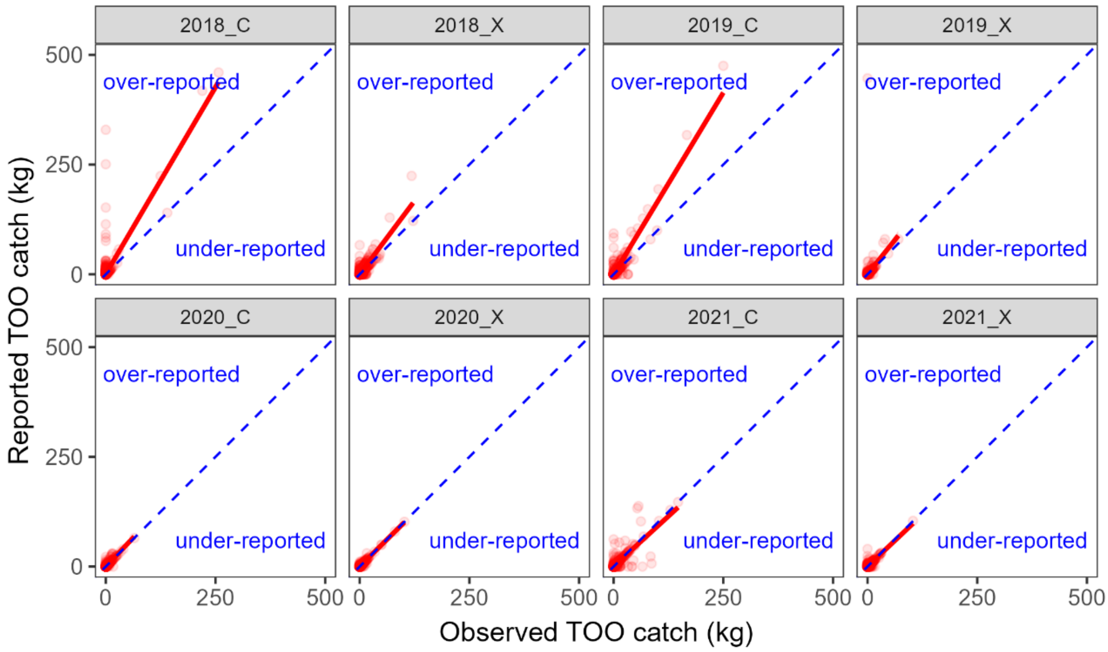

Figure 14. Contract observer vs. e-logbook toothfish bycatch per haul (red points) in the calamari trawl fishery during 2018-2021. Linear models (red lines with 95% CI) were fitted to facilitate comparison against 'reported = observed' lines (dashed blue lines).

Compared to FIFD observer data (Figure 11), a similar level of over-reporting in 2019_C, as well as correct reporting in 2020-2021, was noted by contract observers. However, FIFD data did not show over-reporting in 2018_C, 2018_X and 2019_X. To elucidate the source of these differences, a more detailed exploration of contract observer data was conducted by disaggregating plots in Figure 14 per vessel; the complete set of plots is given in Appendix 1. Here only the results for season 2019_C are presented as an example (Figure 15). Most of the over-reporting in 2019_C (anything above the blue striped line) was attributed to three vessels (vessel_2, vessel_5 and vessel_17); however, most of the reported toothfish catches on these three vessels were exactly 1.9 times higher than the observed catches (all values along black dotted lines, marked by green arrows). Given that 1.9 is toothfish CF in trawl fisheries, it is strongly suspected that the mentioned vessels erroneously applied CF to what was already a green weight (as described in the previous chapter). This occurred on several occasions during 2018-2019 and ended with a single case in 2020_C, with no similar mistakes found since; this accounts for most of the 'over-reporting' found in the analysis. Another, less prominent, source of 'over-reporting' appeared during the first year of a contract observer programme (Figure A.1, blue arrows), when several vessels reported toothfish bycatch on multiple occasions, while observers haven't reported any; this would suggest that some observers were not monitoring toothfish bycatch at the time, and in this case, vessel-reported data should be considered more reliable (i.e. this was the case of observer under-reporting).

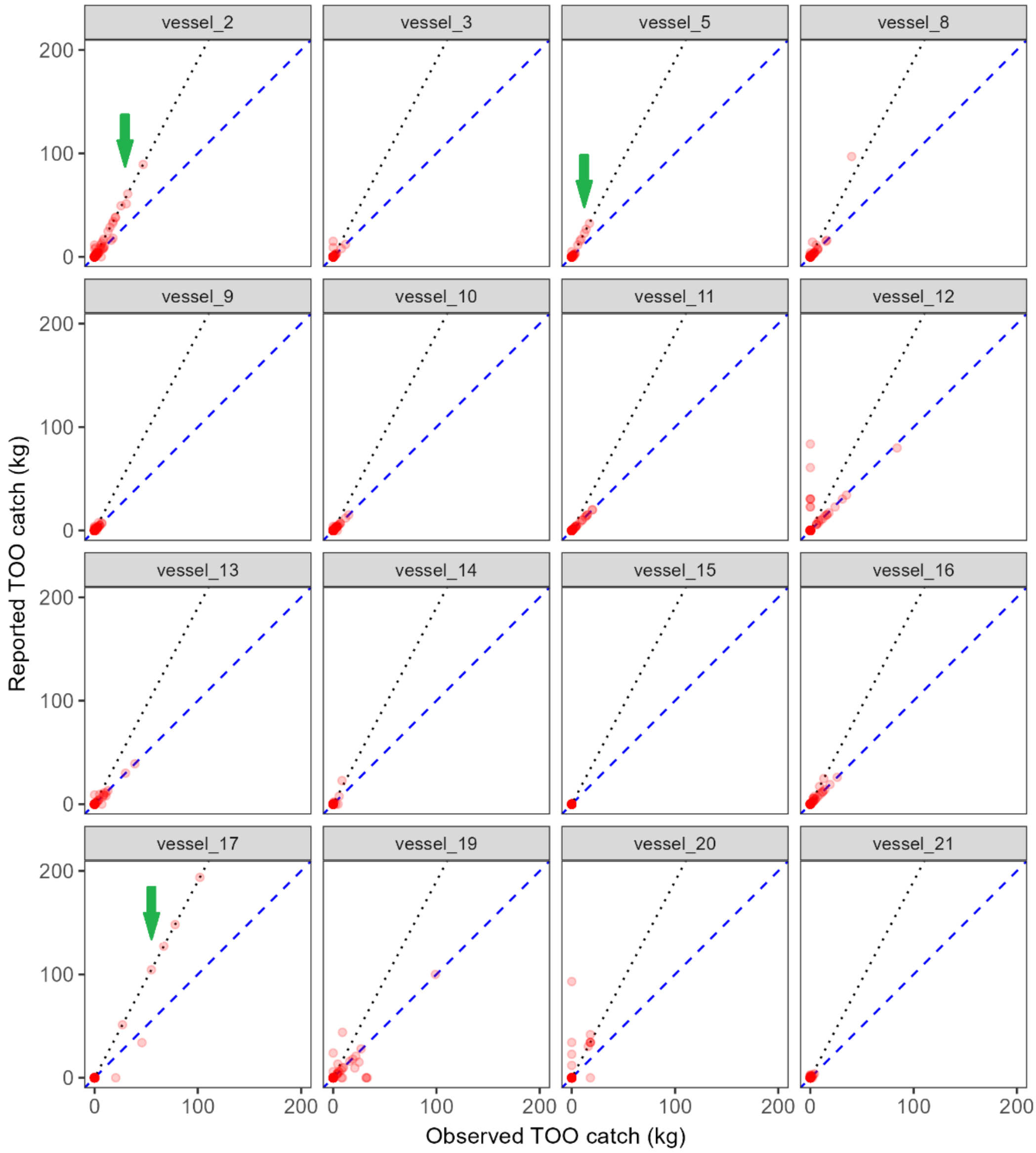

Figure 15. Contract observer vs. e-logbook toothfish bycatch per haul (red points) in the calamari trawl fishery during season 2019_C, per vessel. Dashed blue lines denote reported = observed bycatch. Doted lines denote reported = 1.9 * observed bycatch. Green arrows point out the data for which erroneous use of conversion factor is suspected.

To assess whether the data suspected of erroneous application of CF could be corrected objectively, the ratio of observed to reported toothfish bycatch was plotted against cumulative day-in-season, providing a temporal context to the data; the complete set of plots is given in Appendix 2. Here only a small subset of the data is presented as an example (Figure 16); vessel_3 had an almost perfect match between observed and reported TOO bycatch in all three presented seasons (points along blue lines), while vessel_2 and vessel_5 started over-reporting (*1.9) after the first few days of 2018_X and carried over this practice to the first half of 2019_C (points along red lines, marked by green arrows). Interestingly, the practice started and ended at approximately the same times on both vessels, suggesting it was communicated either between vessel operators or between observers. Examination of the complete set of plots (Figure A.2) confirms that similar to Figure 16, most cases suspected of erroneous application of CF occurred in well-defined timeframes, which could be used as an objective criterion when choosing which data to retroactively correct (e.g. all reports by a selected vessel in a selected time-frame).

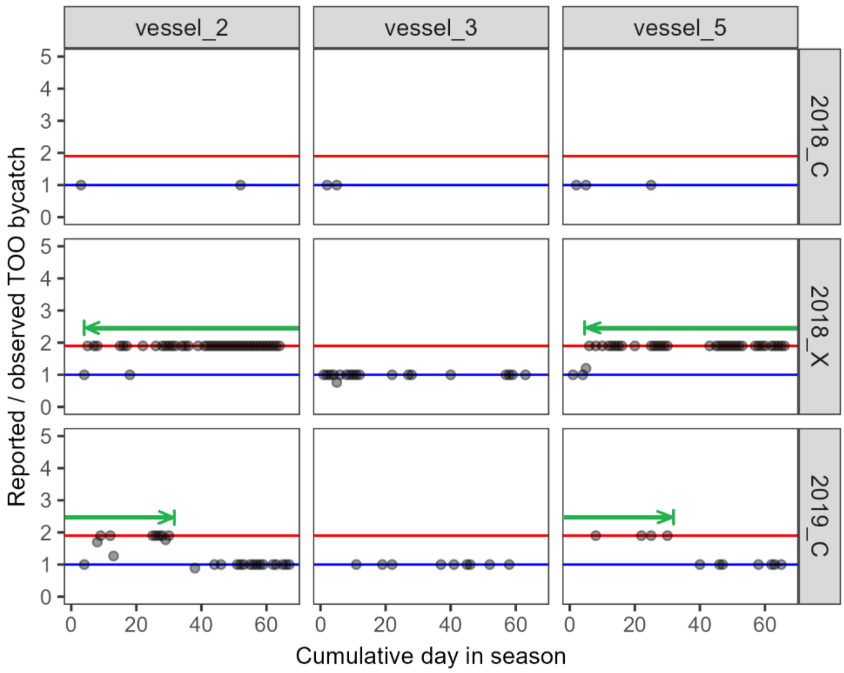

Figure 16. Reported / observed toothfish bycatch per haul over time (black points), for selected sub-sample of vessels and seasons. Blue lines denote reported = observed bycatch. Red lines denote reported = 1.9 * observed bycatch. Green arrows point out periods suspect of erroneous use of conversion factor.

To estimate the magnitude of erroneous reporting, the absolute and relative differences between the total observed and reported toothfish bycatch per season were explored (Figures 17 and 18). Figure 17 was produced from uncorrected data; statistically significant over-reporting was found in all but one season (Figure 17.B). Both absolute and relative over-reporting was much higher during the first four seasons compared to the last four seasons, with a prominent peak in the first season. However, the previous analysis showed that over-reporting was partially due to the erroneous use of CF, and this could potentially mask any other erroneous reporting trends. Therefore, the analysis was repeated using the corrected data wherever erroneous use of CF was suspected (9 vessels in 11 seasons, marked by green arrows in Figure A.2). After correction, a high level of over-reporting remained only in 2018_C and 2019_X (Figure 18). As already mentioned, the supposed over-reporting in 2018_C was most likely a case of under-reporting by contract observers, while over-reporting in 2019_X could be traced to a single haul where 446.5 kg of toothfish was reported, but not observed. The remaining six seasons showed an overall good match between reported and observed data, although with slight but persistent over-reporting; at least two factors could have contributed to this: i) vessels were pooling toothfish bycatch over multiple hauls, some of them unobserved, and 2) not all cases of erroneous use of conversion factor were corrected, especially isolated occurrences. Nevertheless, erroneous reporting could overall be described as insignificant (practically, if not always statistically) in all seasons but 2018_C and 2019_X.

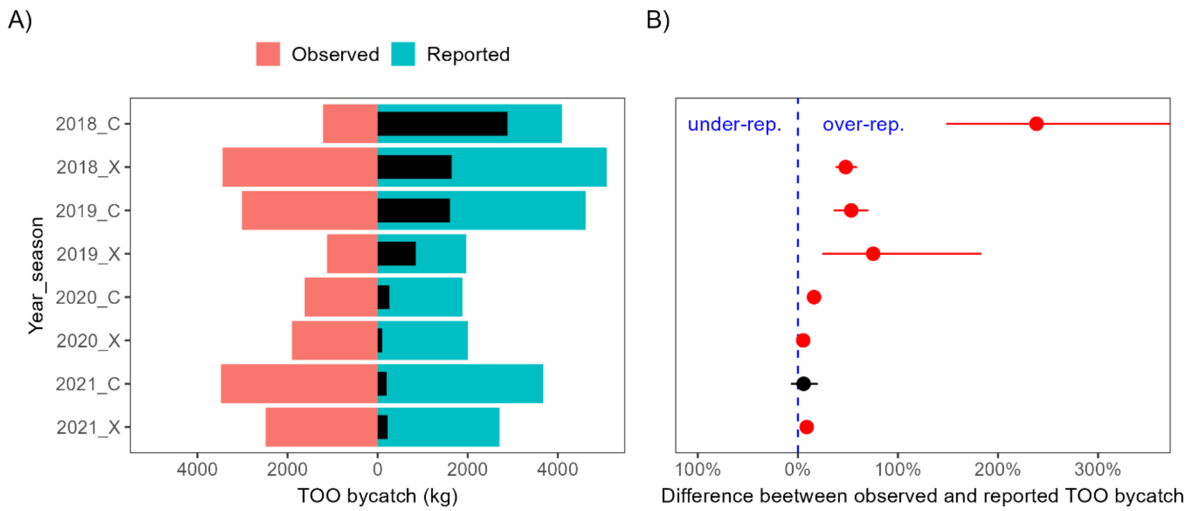

Figure 17. A) Total observed and reported toothfish bycatch in the calamari trawl fishery during 2018-2021, with absolute differences between the two denoted by black lines. B) Relative differences between observed and reported toothfish bycatch, calculated as (reported – observed) / observed; dots are empirical (observed) values, horizontal lines are bootstrapped 95% CI.

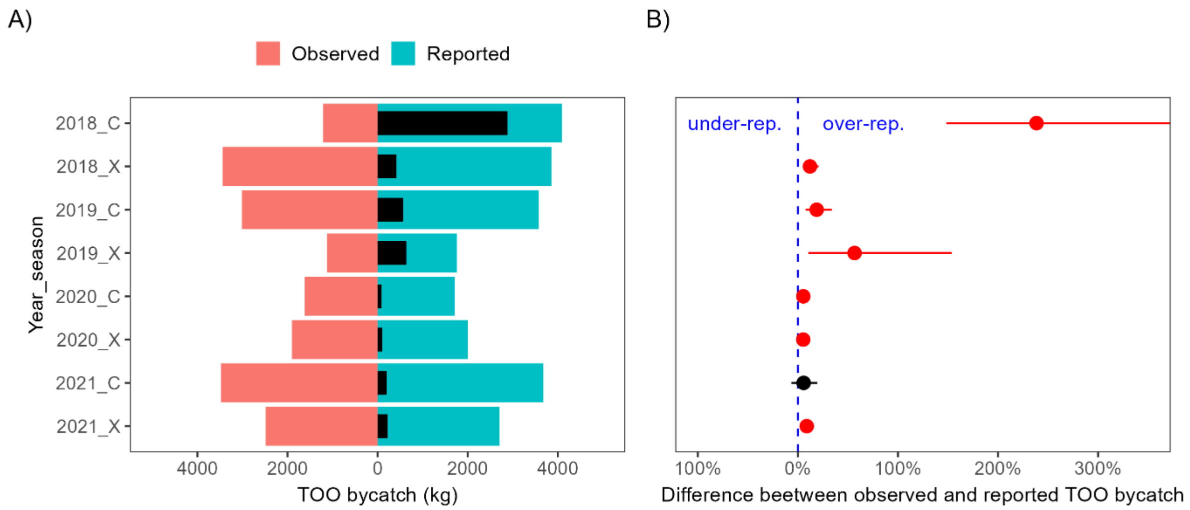

Figure 18. The same as Figure 17 but using corrected data.

For corrected data only, vessel-disaggregated observed and reported toothfish bycatch per season are given in Figure 19. It shows that over-reporting in 2018_C was recorded on most vessels, including 7 vessels for which no toothfish was observed at all; this suggests that the protocol was not uniform among observers and some were not monitoring toothfish bycatch. Over-reporting in 2019_X belonged to a single large unobserved catch on vessel_12. Minor over-reporting in 2019_C belonged to ~5 moderately large reported but unobserved toothfish catches on vessel_12 and vessel_20; these could be the case of vessel pooling bycatch over multiple (including unobserved) hauls. None of the above-mentioned over-reported hauls indicated erroneous use of CF, suggesting that data corrections removed most of the CF-induced over-reporting.

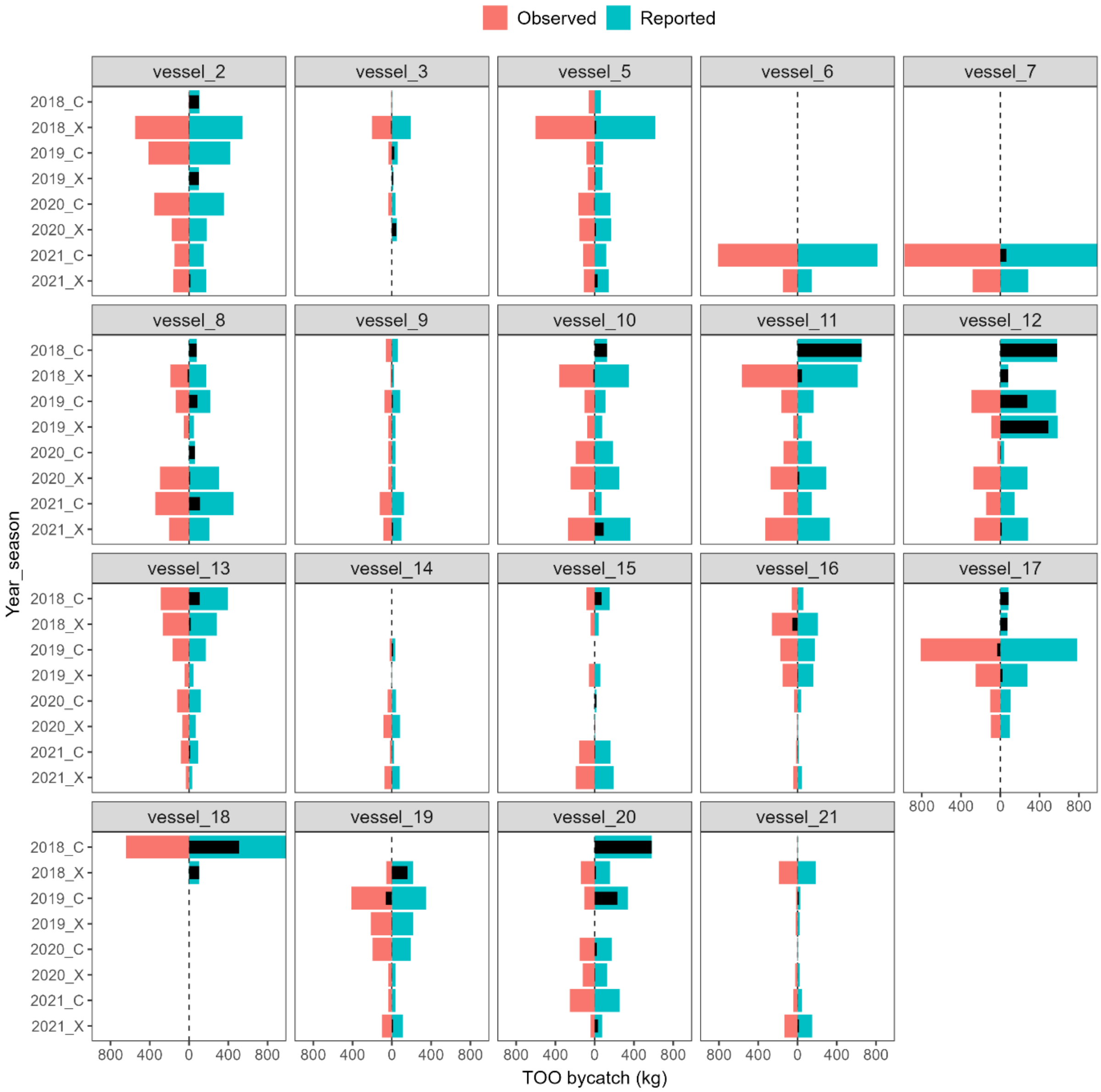

Figure 19. Total observed and reported toothfish bycatch in the calamari trawl fishery during 2018-2021, per vessel, with absolute differences between the two denoted by black lines.

3.3.3. Overview

A brief overview of toothfish bycatch self-reporting (e-logbook) and monitoring practices (FIFD and contract observers), in the calamari trawl fishery during 2017-2021, is given in Table 2.

Table 2. Summary of toothfish bycatch reporting and monitoring practice in the calamari trawl fishery in 2017-2021.

Season	Description	Action (taken or suggested)
2017_C	No apparent erroneous reporting, but the season had no contract observer coverage, and had FIFD coverage on four vessels only.	Coverage was increased in following seasons, leading to more reliable estimates.
2017_X	Under-reporting by the fishery, based on FIFD coverage over 15 vessels (although for comparatively short period on most of them). This was the season with the second highest toothfish bycatch over the last 10 years, possibly contributing to under-reporting.	Reported total toothfish bycatch should be raised by the level of under-reporting for the use in stock assessment.
2018_C	Apparent over-reporting by the fishery (according to contract observer data); likely the case of under-reporting by contract observers (initial phase of the programme, focus on marine mammals).	Issue has not occurred in following seasons, suggesting that it was resolved.
2018_X 2019_C 2019_X 2020_C	Over-reporting by the fishery; traced largely to the erroneous use of conversion factor on some vessels. Once corrected for this, the remaining few cases of notable over-reporting were traced to a few individual hauls with large (unobserved) bycatch; an exception rather than the rule.	Issue has not occurred in following seasons, suggesting that it was resolved. Option of retroactively correcting data in the database should be discussed at FIFD.
2020_X 2021_C 2021_X	Very good match between e-logbook data and both FIFD and contract observer data. Presumably both contract observer programme and e-logbook programme are well established by now, leading to a more uniform practice.	See below.

Most of the issues regarding erroneous reporting (either by the fishery or observers) have been gradually resolved over 2017-2021, as fishery monitoring evolved. However, further improvements should be considered in the future, primarily related to contract observer duties. Unlike FIFD observers, contract observers are not required to conduct sampling in the factory but instead rely on the vessel (crew/ factory manager) to collect toothfish samples for them. Such protocol is, in effect, closer to a vessel estimate than to an independent observer estimate. We can presume that the effort put by the crew into collecting toothfish will be vessel- and haul size-specific, i.e. during large catches and no active observer presence in the factory, retrieving toothfish catch (particularly of small new recruits) on the sorting belt will unlikely be prioritised. All seasons since the inception of the contract observer programme had seen weak toothfish recruitment, and bycatches were consequently very low and tended to consist of larger fish that are more reliably reported; this makes it easier for the crew to collect toothfish and removes any incentive to intentionally under-report (as the move-on rule would be almost impossible to trigger). Indeed, since 2018, over-reporting by the fishery seems to be much more prevalent than under-reporting. However, this could all change in the case of a high-recruitment year, with high bycatches of very small toothfish; 2017_X is a good example of widespread under-reporting in a similar scenario. Therefore, it would be prudent to pre-emptively adjust the contract observer protocol to include more extensive sampling in the factory and thus obtain independent toothfish bycatch estimates.

Another issue that requires further consideration is the observers' practice to share bycatch information with the vessels they are on. This likely results in an inflated proportion of exact matches between the observed and reported toothfish bycatch during the observed hauls, but makes it difficult to meaningfully extrapolate to the unobserved hauls, i.e. we would underestimate the true extent of discrepancy between the toothfish bycatch as perceived by the vessel and by the observer. The alternative of observers not sharing bycatch information with vessels would lead to better (more impartial) data but might be perceived negatively by the industry; this needs to be further discussed at FIFD.

3.4. Toothfish bycatch move-on rule

3.4.1. Overview

During the last quarter (October to December) of 2015 to 2017, grenadier catches in the finfish trawl fishery increased; by 2017, it became apparent that several vessels were targeting grenadier in deeper waters in the southwest of the FICZ under W-licence (Randhawa 2020). This area overlaps with an important toothfish ontogenetic migratory pathway linking the southern shelf-based recruitment and Burdwood Bank deep-water spawning habitats (Lee *et al.* 2021). Because of this change in fishing behaviour, toothfish bycatch in the finfish trawl fishery increased to record levels in 2016 and 2017. However, despite high toothfish catches, the 10% bycatch was rarely exceeded in this period due to the significant catches of grenadiers (not considered a bycatch species at the time). The FIFD responded by lowering the toothfish bycatch threshold to 1.5% of the total catch (previously set at 10%) and enforcing a move-on rule (a vessel reaching this threshold cannot return to this grid square until a full ten-day period has passed) (Randhawa 2020). The new regulation was enforced in February 2018, and even though it was motivated by high toothfish bycatch in the finfish trawl fishery, it applied to the calamari trawl fishery as well.

From the available documentation, it wasn't obvious how the threshold of 1.5% was chosen, but presumably, it was with the finfish trawl fishery in mind. The two trawl fisheries exploit different parts of the toothfish population in different areas: finfish trawling occurs on the shelf primarily north and west of the Falkland Islands, and calamari trawling on the shelf south and east of the Falkland Islands (Skeljo *et al.* 2022). The main differences between the two fisheries regarding toothfish bycatch are summarised in Figures 20-22. The calamari trawl fishery operates over a much narrower and overall shallower depth range and experiences less toothfish bycatch in terms of weight (Figure 20). Given toothfish ontogenetic migration, smaller fish are caught in shallower waters, leading to a distinct toothfish bycatch size-structure between the two fisheries (Figure 21); the difference in the average toothfish weight is especially important, with toothfish in the finfish fishery being on average 4-times heavier than in the calamari fishery. This implies that enforcing a move-on rule based on a proportion of bycatch weight in the total catch (e.g. 1.5% threshold) affects the two fisheries differently, being more relevant in the finfish fishery (Figure 22); in the last five years, the threshold has been exceeded on 16 out of 9392 vessel-days in the calamari fishery, compared to 965 out of 8504 vessel-days in the finfish fishery.

A comparison of toothfish bycatch in the calamari and finfish trawl fisheries suggests that a single move-on rule might not be appropriate for both; for the calamari trawl fishery, this issue is explored in more detail further in the report.

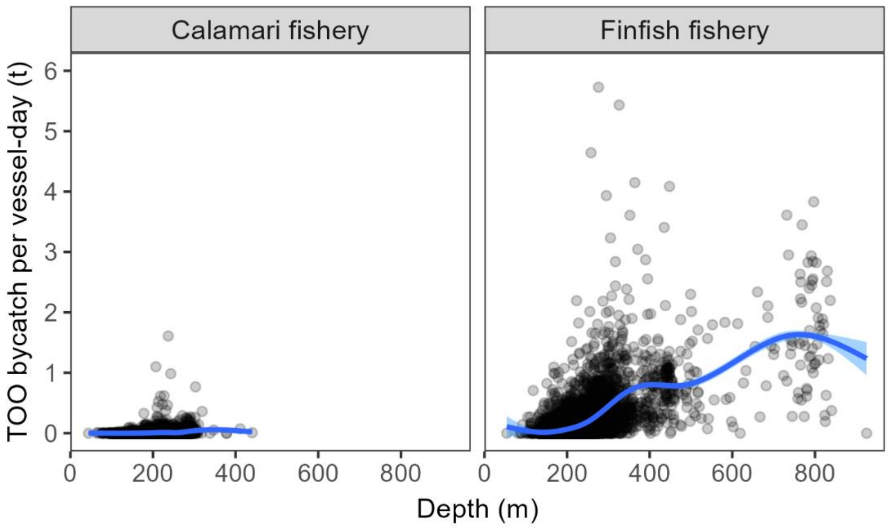

Figure 20. Toothfish bycatch per vessel-day against fishing depth, in the calamari and finfish trawl fisheries (2017-2021). Smoothers (cubic splines) are added to aid visual interpretation of trends.

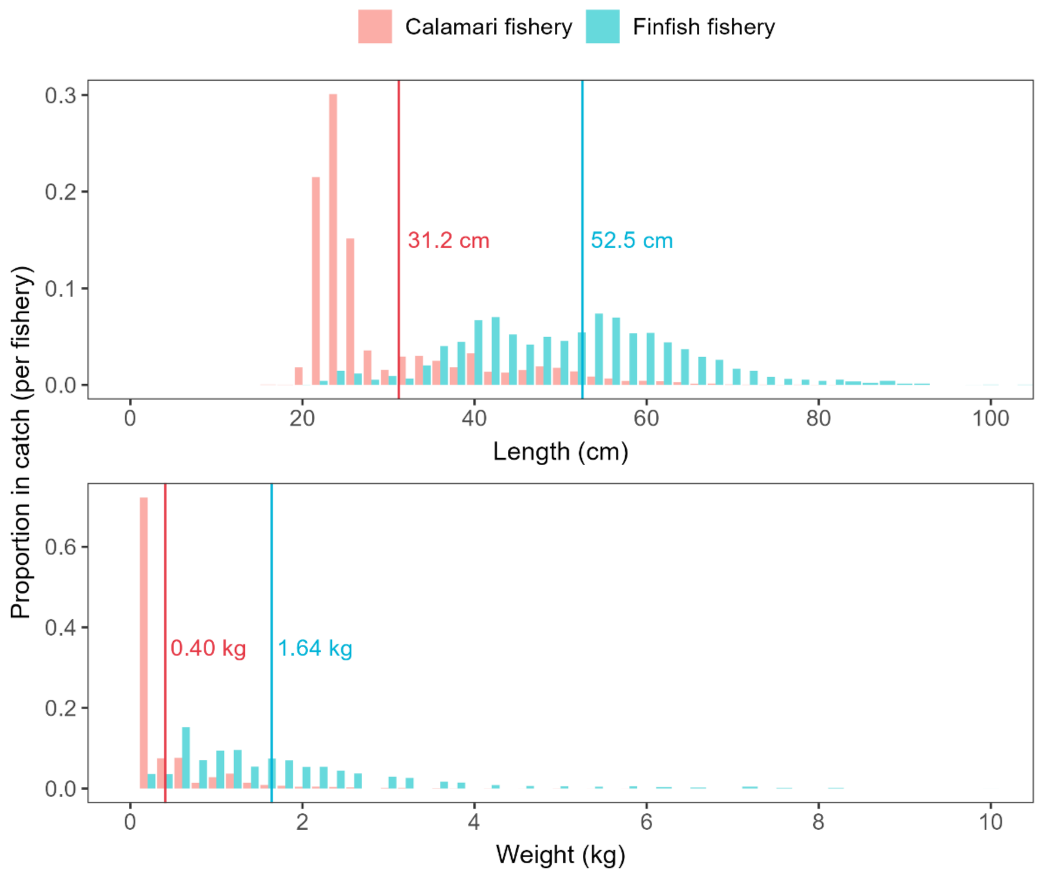

Figure 21. Size distribution of toothfish bycatch in the calamari and finfish trawl fisheries, during 2017-2021. Vertical lines denote average length (top) and weight (bottom) of toothfish bycatch in the two fisheries.

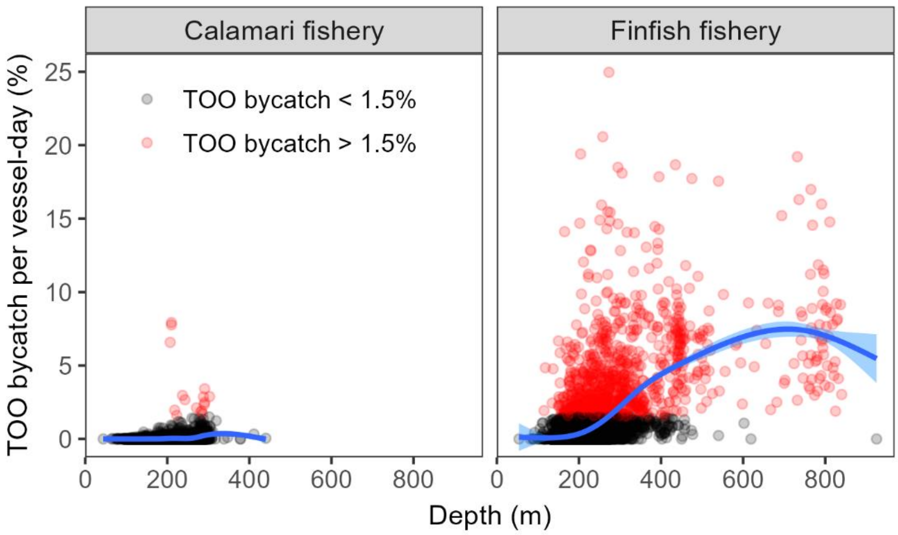

Figure 22. Toothfish bycatch proportion per vessel-day against fishing depth, in the calamari and finfish trawl fisheries (2017-2021). Vessel-days with toothfish bycatch weights above the 1.5% threshold are highlighted in red. Smoothers (cubic-splines) are added to aid visual interpretation of trends.

3.4.2. Move-on rule in the calamari trawl fishery

As shown in chapter 3.2, toothfish bycatch in the calamari fishery has been primarily driven by recruitment, i.e. strong toothfish cohort(s) supported high bycatch over a few years, before leaving the fishery area due to ontogenetic migration. The introduction of the 1.5% move-on rule in February 2018 coincided with the start of a prolonged period of weak toothfish recruitments (2018-2021); low recruitment leads to low bycatch, and the move-on rule was triggered only twice in the calamari trawl fishery during this entire period. One of those cases was due to vessel over-reporting (erroneous use of conversion factor), leaving a single vessel-day that correctly triggered the move-on rule over 8 seasons and 7415 vessel-days. This made it difficult to evaluate the usefulness of the rule in the calamari trawl fishery, as it has never been tested in a high-bycatch season; the fact that it hasn't been triggered during low-bycatch seasons might even be considered advantageous. Some insight was gained by examining historical toothfish bycatch proportions per vessel-day in the calamari trawl fishery during 2016-2021 (Figure 24); earlier years were excluded due to infrequent toothfish reporting (and of large catches only).

Figure 24 revealed large differences in bycatch frequency distributions between high- and low-bycatch years; the highest number of vessel-days with >1.5% toothfish bycatch was recorded in 2016 (C + X; 16 + 31), followed by 2017 (3 + 12), while years 2018 to 2021 had altogether one vessel-day with >1.5% toothfish bycatch (baring one erroneous report). This suggests that the existing rule would have been more relevant in high-bycatch years. However, caution is necessary when interpreting the results pertaining to 2016-2017; firstly, the move-on rule was not enforced at the time, and we cannot equate the number of days that had >1.5% toothfish bycatch with the number of times the move-on rule would have been triggered; if the rule had been enforced the actual number of >1.5% bycatch days might have been lower (e.g. vessels would avoid high-bycatch areas). Secondly, reported data for 2016-2017 are not fully reliable; bycatch was under-reported in 2017 (chapter 3.3.1) and the same could be suspected of 2016 (although this is uncertain, due to low observer coverage at the time). However, these were the only two high-bycatch years and were included here so the move-on rule could be evaluated in both low- and high-bycatch scenarios.

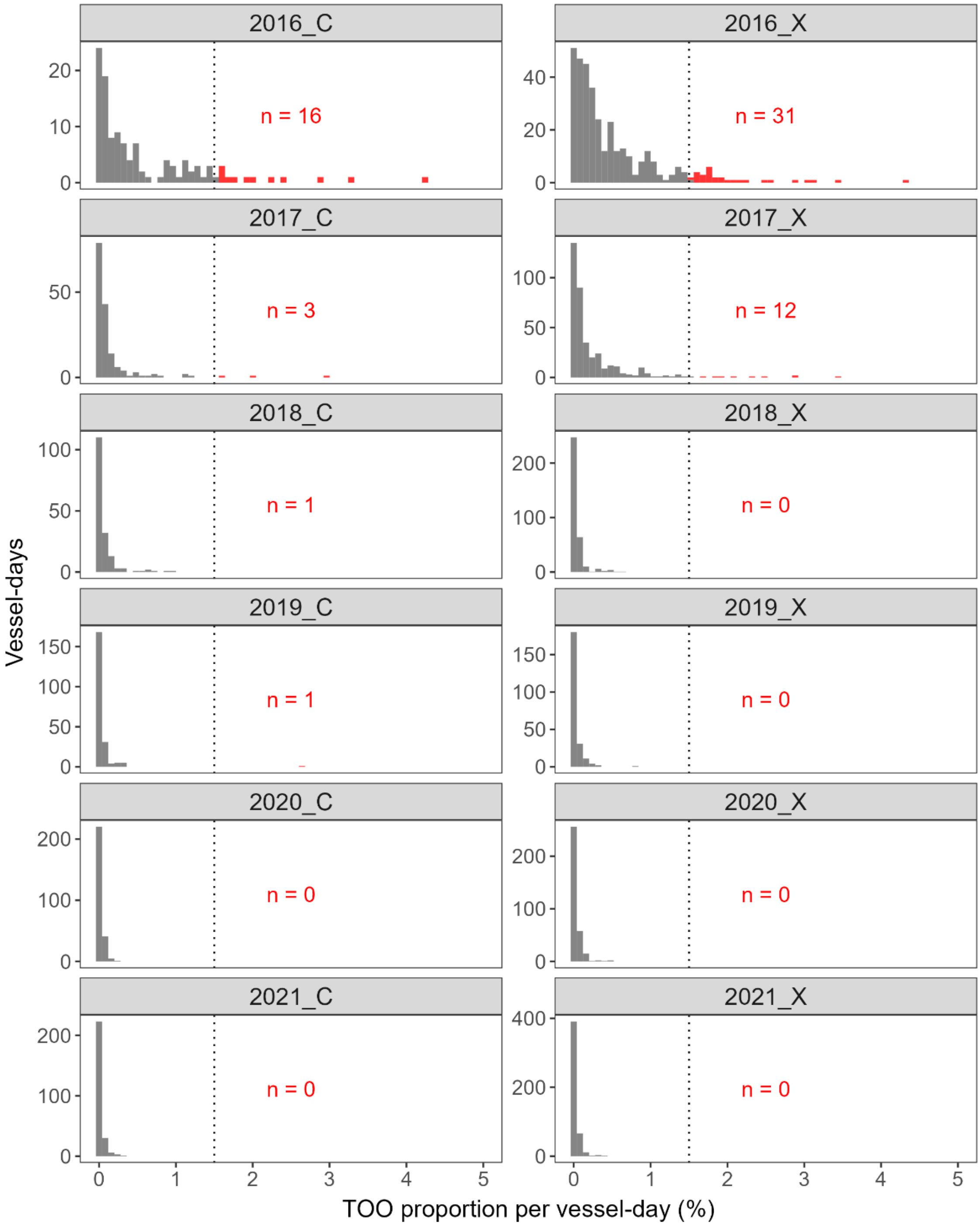

Figure 23. Frequency of toothfish bycatch proportions per vessel-day in the calamari trawl fishery, during 2016-2021. Note that zero catches were excluded to make plots more readable; what appears to be zero on the plots are actually very low non-zero values. Doted lines denote 1.5% bycatch threshold. Number of vessel-days with toothfish bycatch above 1.5% threshold is given in red.

Evaluating the effectiveness of the 1.5%-threshold in the calamari trawl fishery is difficult, because the rule was not enforced in high-bycatch years when it could have made an impact, and in low-bycatch years it was enforced but practically never triggered. It is unclear if this threshold was ever considered in the context of the calamari trawl fishery. As an alternative, a range of potential move-on rule thresholds appropriate for the calamari fishery was explored, via the analysis of cumulative bycatch curves.

Figure 24 presents cumulative toothfish bycatch curves for pooled data from 2016-2021; bycatch was expressed in terms of absolute weight (left) and relative weight (right). Vessel-days with zero toothfish bycatch were excluded. Curves were dominated by a high number of low bycatches; for example, 80% of non-zero toothfish bycatches were below 32 kg or 0.1% of the total catch (80^{th} percentile in Figure 24). Numerous low bycatches predominantly belonged to low-bycatch years (2018-2021), when the combination of weak toothfish recruitment and increased observer coverage lead to more frequent reporting. Because of this, pooled cumulative bycatch curves resulted in low estimated reference thresholds: 53 kg or 0.25% according to *Seg. reg.* method, and 111 kg or 0.52% according to *(0, 1) Dist.* method and *Youden index*. These values are well below the currently enforced 1.5% threshold; however, they are perhaps too heavily influenced by the data from low-bycatch years.

To further explore this, cumulative bycatch curves were disaggregated per season (Figure 25). Both absolute (Figure 25.A) and relative (Figure 25.B) curves could be divided into three distinct groups:

- <u>2016</u>: cumulative curves lacked a clearly defined area distinguishing between the initial and the asymptotic part of the curve; this translated to a comparatively wide range of estimated threshold values between the three methods. Estimated thresholds were the highest of any analysed year: 138 - 297 kg, and 0.95 - 1.75% of the total catch (Table 3). The major deficiency of 2016 data was a suspected non-reporting of small bycatches (Chapter 3.3); this was the period when increased toothfish monitoring was only starting to pick up. If small bycatches went unreported, the shape of the cumulative curve would have been affected, resulting in inflated thresholds.
- <u>2017</u>: cumulative curves had better-defined areas distinguishing between the initial and the asymptotic part of the curve; this translated to similar estimated threshold values between the three methods. Estimated thresholds were in-between 2016 and 2018-2021 estimates: 101 - 162 kg, and 0.25 - 0.88% of the total catch (Table 3). The main deficiency of 2017 data was under-reporting, as confirmed by the observed data.
- <u>2018-2021</u>: cumulative curves had well-defined areas distinguishing between the initial and the asymptotic part of the curve; this translated to almost identical estimated threshold values between the three methods. Estimated thresholds were low: 12 - 55 kg, and 0.03 - 0.35% of the total catch (Table 3). This period had the most accurate toothfish bycatch reporting due to full observer coverage. However, the deficiency of the 2018-2021 data is that it belongs entirely to low-bycatch years, resulting in thresholds that might be too conservative for high-bycatch years (i.e. triggered too often, disrupting the fishing practice).

Overall, each group produced a distinct range of potential thresholds (with very little overlap between the three), but each was also associated with a unique caveat. This makes it difficult to recommend a single threshold value; instead, a range of potential values should be discussed at FIFD, and a value chosen as a compromise between the need to protect juvenile toothfish and the need to minimise the disruptions to commercial activities. Here, a range of relative threshold values between 0.5% and 1.0%, and absolute threshold values between 100 and 200 kg, is proposed for further consideration in the calamari trawl fishery.

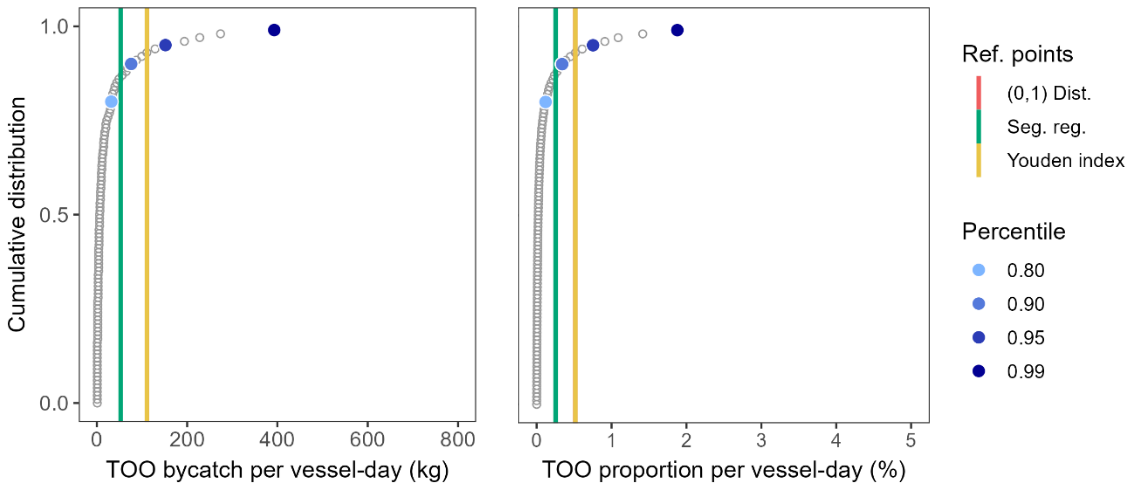

Figure 24. Cumulative distributions of absolute and relative toothfish bycatch per vessel-day, as reported by the fishery, during 2016-2021. The reference points for each season were calculated using: the '(0,1) distance' method (red line, hidden behind the yellow line), 3-parameter segmented regression (green line), and the Youden index (yellow line). Blue points denote percentiles of bycatch data. Note that the x-axis was limited to 800 kg and 5% to make the plots more uniform and readable; because of this, one datapoint corresponding to very large toothfish bycatch of 1609 kg (8% of the total catch), corresponding to 1.00 percentile, was omitted from the figure but was included in the analysis.

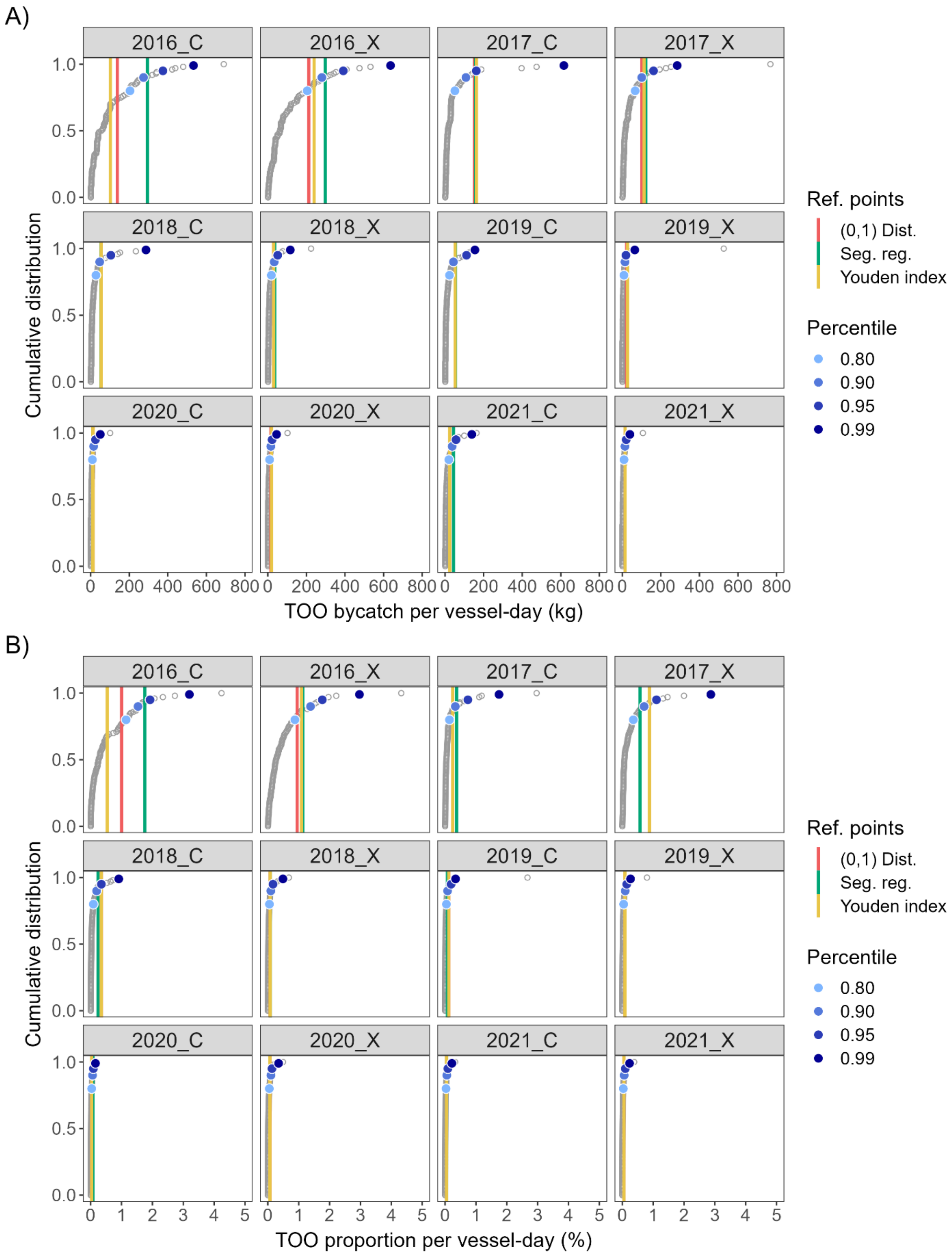

Figure 25. Cumulative distributions of A) absolute and B) relative toothfish bycatch per vessel-day, as reported by the fishery, per season. The reference points for each season were calculated using: the '(0,1) distance' method (red line), 3-parameter segmented regression (green line), and the Youden index (yellow line). Blue points denote percentiles of bycatch data. Note that the x-axis was limited to 800 kg and 5% to make the plots more uniform and readable; because of this, a few data points corresponding to very large catches were omitted from the figure but were included in the analysis.

Table 3. Selected percentiles and the three estimated reference thresholds for move-on rule in the calamari trawl fishery, in terms of toothfish bycatch weight (kg) and proportion in total catch (%).

	Year-season	Percentiles				Reference thresholds		
		0.80	0.90	0.95	0.99	(0, 1) Dist.	Seg. reg.	Youden index
(kg)	2016_C	204	274	375	533	138	295	102
	2016_X	204	280	391	636	212	297	240
	2017_C	51	108	162	616	152	158	162
	2017_X	67	101	162	285	101	122	113
	2018_C	27	47	105	287	55	53	55
	2018_X	18	33	51	116	30	36	30
	2019_C	23	43	111	155	52	54	52
	2019_X	8	14	19	65	23	-	27
	2020_C	9	15	25	50	13	12	12
	2020_X	9	16	22	45	16	-	19
	2021_C	20	37	57	139	24	44	24
	2021_X	9	14	20	40	15	-	15
	Pooled	32	76	152	393	111	53	111
(%)	2016_C	1.15	1.54	1.92	3.20	1.00	1.75	0.54
	2016_X	0.88	1.38	1.76	2.97	0.95	1.13	1.09
	2017_C	0.14	0.33	0.74	1.75	0.25	0.38	0.25
	2017_X	0.36	0.71	1.11	2.87	0.88	0.58	0.88
	2018_C	0.09	0.19	0.35	0.91	0.35	0.24	0.35
	2018_X	0.05	0.10	0.17	0.49	0.07	0.08	0.07
	2019_C	0.04	0.08	0.20	0.34	0.12	0.08	0.12
	2019_X	0.04	0.10	0.15	0.27	0.08	0.10	0.08
	2020_C	0.03	0.06	0.09	0.16	0.03	0.07	0.03
	2020_X	0.05	0.10	0.13	0.35	0.07	0.07	0.07
	2021_C	0.03	0.06	0.09	0.22	0.05	0.05	0.05
	2021_X	0.03	0.06	0.10	0.24	0.05	0.06	0.05
	Pooled	0.12	0.34	0.75	1.88	0.52	0.25	0.52

To facilitate the discussion on potential threshold values appropriate for the calamari trawl fishery, a selection of proposed absolute and relative threshold values was applied to historical bycatch data from 2016-2021 (Tables 4 and 5). The limitation of this approach was already outlined; applying the rule retroactively to the bycatch taken at the time when the rule was not enforced is approximate at best. However, it does allow for a (limited) comparison of different thresholds, in terms of their potential impact on commercial activities.

The proposed range of absolute thresholds would lead to different levels of impact on the fishery, but only in high-bycatch years (2016-2017); the lowest proposed threshold (100 kg) would be exceeded approximately three times more often than the highest proposed threshold (250 kg) (Table 4). In contrast, proposed thresholds would have very little effect during low-bycatch years (2018-2021), as toothfish bycatches rarely exceeded even the lowest threshold. This was expected, as the proposed threshold range was chosen to provide good contrast in high-bycatch years when it would matter the most.

The proposed range of relative thresholds showed a similar trend as absolute thresholds. In high-bycatch years, the lowest proposed threshold (0.5%) would be exceeded approximately twice as often as the highest proposed threshold (1.0%), and in low-bycatch years even the lowest threshold would be rarely exceeded. Note that the highest proposed threshold (1.0%) would be exceeded approximately twice as often as the currently enforced 1.5% threshold.

Finally, a comparison of absolute and relative thresholds showed that some could be paired based on the expected impact on commercial activities, i.e. would be exceeded a similar number of times per year-season: 100 kg roughly corresponded to 0.5%, 200 kg to 1.0%, and 250 kg to the currently enforced 1.5% threshold.

Table 4. Number of vessel-days with toothfish bycatch above selected absolute thresholds (100, 150, 200 and 250 kg) in the calamari trawl fishery, per year-season. The 250 kg threshold would have a similar impact on commercial activities as the currently enforced 1.5% threshold and is provided for comparison.

Year-season	Vessel-days	No. vessel-days above threshold (% from total is given in brackets)			
		100 kg	150 kg	200 kg	250 kg
2016_C	1020	40 (3.9%)	30 (2.9%)	26 (2.5%)	14 (1.4%)
2016_X	1004	128 (12.7%)	100 (10.0%)	71 (7.1%)	47 (4.7%)
2017_C	997	19 (1.9%)	11 (1.1%)	7 (0.7%)	6 (0.6%)
2017_X	1000	40 (4.0%)	21 (2.1%)	14 (1.4%)	8 (0.8%)
2018_C	975	10 (1.0%)	7 (0.7%)	5 (0.5%)	4 (0.4%)
2018_X	977	5 (0.5%)	1 (0.1%)	1 (0.1%)	0
2019_C	953	12 (1.3%)	3 (0.3%)	2 (0.2%)	1 (0.1%)
2019_X	635	1 (0.2%)	1 (0.2%)	1 (0.2%)	1 (0.2%)
2020_C	1012	1 (0.1%)	0	0	0
2020_X	993	1 (0.1%)	0	0	0
2021_C	891	6 (0.7%)	1 (0.1%)	0	0
2021_X	979	1 (0.1%)	0	0	0

Table 5. Number of vessel-days with toothfish bycatch above selected relative thresholds (0.5, 0.6, 0.7, 0.8, 0.9 and 1.0% of the total catch) in the calamari trawl fishery, per year-season. The currently enforced threshold of 1.5% is provided in the last column, for comparison.

Year-season	Vessel-days	No. vessel-days above threshold (% from total is given in brackets)						
		0.5%	0.6%	0.7%	0.8%	0.9%	1.0%	1.5%
2016_C	1020	42 (4.1%)	36 (3.5%)	36 (3.5%)	35 (3.4%)	34 (3.3%)	29 (2.8%)	16 (1.6%)
2016_X	1004	129 (12.8%)	106 (10.6%)	95 (9.5%)	81 (8.1%)	73 (7.3%)	59 (5.9%)	31 (3.1%)
2017_C	997	14 (1.4%)	11 (1.1%)	10 (1.0%)	7 (0.7%)	6 (0.6%)	6 (0.6%)	3 (0.3%)
2017_X	1000	62 (6.2%)	50 (5.0%)	41 (4.1%)	38 (3.8%)	33 (3.3%)	24 (2.4%)	12 (1.2%)
2018_C	975	8 (0.8%)	7 (0.7%)	5 (0.5%)	3 (0.3%)	3 (0.3%)	1 (0.1%)	1 (0.1%)
2018_X	977	5 (0.5%)	1 (0.1%)	1 (0.1%)	0	0	0	0
2019_C	953	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.1%)
2019_X	635	1 (0.2%)	1 (0.2%)	1 (0.2%)	1 (0.2%)	0	0	0
2020_C	1012	0	0	0	0	0	0	0
2020_X	993	2 (0.2%)	0	0	0	0	0	0
2021_C	891	0	0	0	0	0	0	0
2021_X	979	0	0	0	0	0	0	0

Due to the nature of toothfish bycatch in the calamari trawl fishery, choosing a single threshold that would be appropriate in all years is exceedingly difficult. Bycatch is primarily driven by strong toothfish cohorts that appear to be infrequent (one strong, and one moderately-strong cohort in the last 10 years); given that cohorts spend only ~3-4 years in the calamari fishery area, periods of high toothfish abundance alternate with periods of low abundance (in-between two strong cohorts). This leads to alternate high- and low-bycatch periods and must be taken into consideration when choosing a single threshold to be enforced. The threshold ranges proposed above (100 - 200 kg and 0.5 - 1.0%) were proposed with high-bycatch years in mind and would have little impact on the fishery in low-bycatch years; therefore, any value in those ranges would apply to every year. In contrast, setting the threshold too low might have little impact in low-bycatch years, but could cause significant disruption to commercial activities in high-bycatch years.

Besides fluctuations in abundance, another consideration is toothfish growth while in the calamari fishery area. Toothfish appear in the fishery already when ~0.5 years old; because of their small size, these fish would contribute very little towards bycatch weight, and the usefulness of the weight-based move-on rule (either absolute or relative) in protecting the population would be questionable. As an example, we can consider the case of the strong 2015 toothfish cohort that passed through the calamari trawl fishery in 2015-2018 (Figure 6; relevant segment reproduced in Figure 26). In their first season, 2015_C, the average size of fish from the 2015 cohort caught in the calamari fishery was 15 cm / 30 g, and over the next two seasons it increased to 22 cm / 92 g to 32 cm / 298 g; the average weight of the fish increased 10-fold in one-year time (2015_C → 2016_C). Hypothetically, if there were no other strong cohorts within this period (i.e. if the entire bycatch was coming from this single cohort), and a move-on rule was set to e.g. 250 kg, it would take 8,333 toothfish to trigger the rule in 2015_C, compared to 2,717 fish in 2015_X, to 839 fish in 2016_C. In this case, identical bycatch weight in different seasons would correspond to very different numbers of fish removed from the population. Note that this 'hypothetical' situation is exactly what can be expected in the future, i.e. when the next strong toothfish cohort enters the calamari fishery area, following 5+ years of weak recruitment. This also suggests that proposed move-on threshold ranges might not be optimal for protecting the youngest toothfish age-class in the calamari fishery, especially during the strong cohort's first season in the fishery; an alternative solution might be a small-scale spatio-temporal closure.

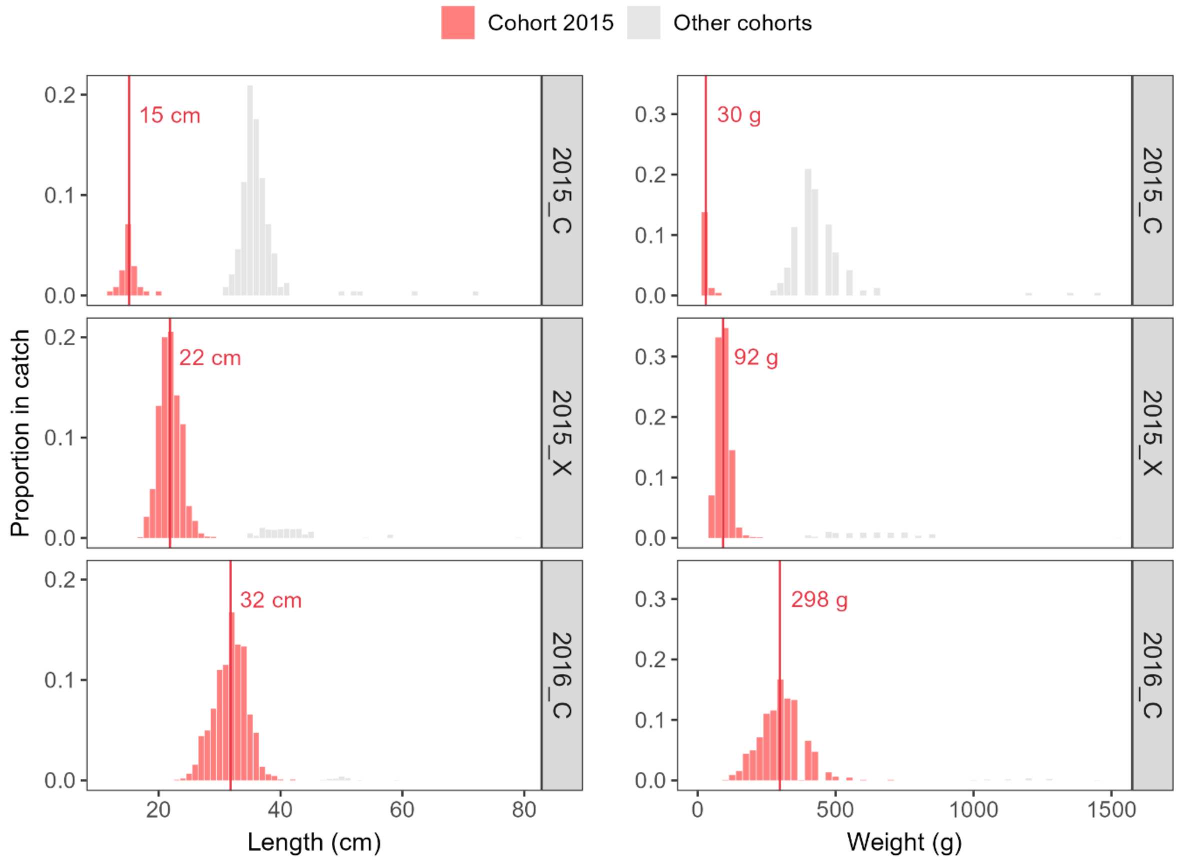

Figure 26. Size distribution of toothfish bycatch in the calamari trawl fishery, for the first three seasons of the strong 2015 cohort (red histograms). Vertical lines denote average lengths (left) and weights (right) of bycatch belonging to cohort-2015, per season.

Research surveys conducted by FIFD (pre-recruitment and groundfish surveys) can provide annual estimates of age-0 toothfish abundance and spatial distribution in advance of the first calamari season (C-season). The spatio-temporal dynamics of juvenile toothfish around the Falkland Islands using survey data have been recently described by Lee *et al.* (2021), using data from 2015-2020; for the full analysis reader is referred to their paper, and here a single figure is reproduced on the spatial distribution of age-0 toothfish in 2015-2017 (Figure 27). Age-0 fish were distributed opportunistically, indicating virtually independent spatial patterns for each of the three years modelled (Lee *et al.* 2021). High variability in the spatial patterns during the three years was clear with hotspots occurring in inshore waters (<200 m) to the south, east, north-east and north-west during 2015, to the north and north-west during 2016 and to the south, west and north-west during 2017. Thus, the only consistent hotspot across the sample period was to the north-west, although the spatial extent and intensity of this hotspot varied for each year (Lee *et al.* 2021). Both strong (2015) and moderately strong (2017) cohorts had hotspots partially overlapping with the calamari fishery area. In 2015, hotspots were spread throughout the fishery area, but in 2017 they overlapped only in the south (incidentally, this was also the area of the highest toothfish abundance). In the 2017 scenario, a spatial closure of even a few (1-2) grid-squares within the Loligo Box might noticeably reduce the impact on the toothfish population, without causing a prohibitive level of disruption to the calamari fishery.

If spatio-temporal closures are considered for the management of the calamari trawl fishery in the future, the C-season pre-recruitment surveys would likely provide the most relevant estimates of age-0 toothfish abundance and spatial distribution. When a strong cohort is detected, a hotspot (if any) could be closed at the onset of the following commercial season; note that this would be on very short notice, so general protocol should be prepared/communicated in advance. Access to the closed area could be allowed periodically for exploratory purposes, with increased observer monitoring of juvenile toothfish bycatch.

The feasibility of enforcing spatio-temporal closure would depend on the abundance and spatial distribution of both squid and toothfish. During years of low toothfish recruitment closure would be unnecessary; during years of high recruitment and low overlap with squid fishery, closure would be a straightforward solution but arguably less important; and during years of high recruitment and high overlap with the squid fishery, closure might be an unpopular measure with the fishery but would be most beneficial for toothfish protection. Given a wide range of potential future scenarios, spatio-temporal closures should be approached flexibly, and discussed on a case-by-case basis.

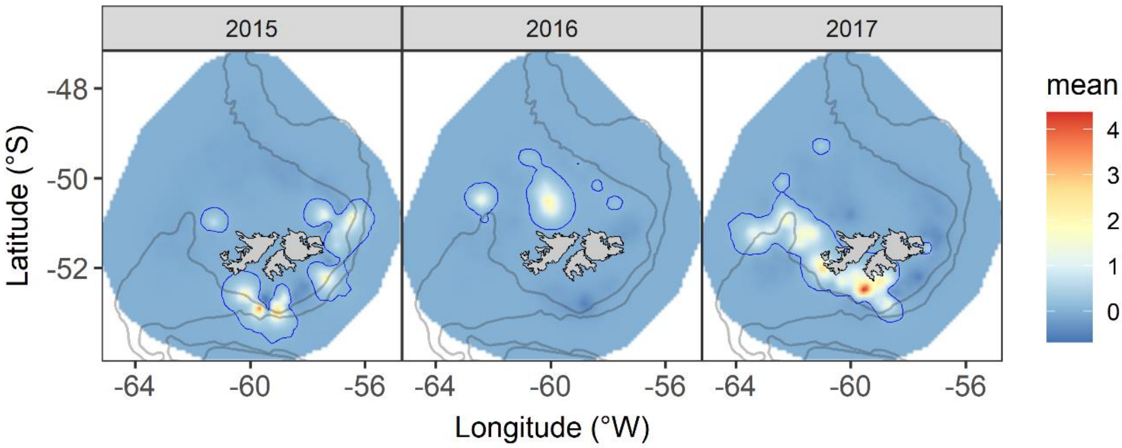

Figure 27. Hotspots of age-0 toothfish abundance during 2015-2017, based on research surveys data. Reproduced from Lee *et al.* (2021).

4. Conclusions

Toothfish bycatch in the calamari trawl fishery, as well as its monitoring and reporting practice, went through three distinct phases over the last ten years. The early period (2012-2015) was characterised by low annual bycatch (<10 t/year), low observer coverage, and infrequent self-reporting by the fishery; it appears daily bycatch was reported only when >50 kg. The transition period (2016-2017) was characterised by a strong peak in toothfish bycatch, from 6 t in 2015 to 52 t in 2016. Analysis of the bycatch size structure showed that the peak was largely driven by catches of 2-year-old fish belonging to the strong cohort that entered the fishery in 2015. In this period self-reporting became more frequent due to both increased catches and increased effort to correctly identify and report toothfish bycatch. Finally, in the recent period (2018-2021) the overall toothfish bycatch reverted to pre-2016 values (<10 t/year) but the reporting frequency further increased and now included even the catches of <1 kg. Increased reporting frequency was primarily driven by the increased observer coverage; starting with 2018, contract observers provided almost full coverage of the fishery.

Comparison of the observed and self-reported toothfish bycatch data was limited to the period 2017-2021, as per-haul data provided by the fishery were sparse in earlier years. In 2017, fishery under-reported by ~30% relative to the FIFD observer data. In 2018-2021, under-reporting appears to have been negligible, but several cases of fishery over-reporting were noticed; these were largely traced to erroneous use of toothfish conversion factor and have been resolved by 2020. In the most recent seasons (2020-2021) there has been a very good match between self-reported data and both FIFD and contract observer data. However, contract observers collect the data in a way that cannot be considered fully independent of the fishery, and changes to their protocol (i.e. introducing dedicated toothfish monitoring directly in the factory) are recommended.

Since 2018, toothfish bycatch in trawl fisheries was regulated via a move-on rule with a 1.5% bycatch threshold. Evaluating the effectiveness of this rule in the context of the calamari trawl fishery proved difficult, as it was introduced in a period of low toothfish recruitment and was seldom triggered in practice. Based on the analysis of cumulative bycatch curves, a range of new potential move-on rule thresholds, appropriate for the calamari fishery, is suggested. These could be either relative (0.5 - 1.0% of toothfish bycatch in the total catch per vessel-day) or absolute (100 - 200 kg of toothfish bycatch per vessel-day). Different values from within these ranges present different levels of a trade-off between the need to protect juvenile toothfish and the need to minimise the disruptions to commercial activities.

Further consideration needs to be given to the protection of the youngest age class; toothfish appear in the calamari trawl fishery already when ~0.5 years old, at an average weight of only ~30 g. Because of their small size, these fish contribute very little towards bycatch weight, and a weight-based move-on rule likely won't have the desired conservation effect. This is especially relevant because all recruitments since 2018 have been weak, and when the next strong recruitment occurs, the bycatch will consist predominantly of the youngest (newly recruited) fish. A small-scale spatio-temporal closure is suggested as an additional solution for the protection of the youngest age class during years with strong recruitment. Work of Lee *et al.* (2021) showed that hotspots of juvenile toothfish distribution around the Falkland Islands can be discerned from survey data; in the case of the calamari trawl fishery, C-season pre-recruitment surveys could provide relevant estimates of age-0 toothfish abundance and spatial distribution, and be used to inform the closure of hotspots (if any) in the coming commercial season.

Due to high recruitment variability, strong toothfish cohorts have to support the longline fishery over a range of years, rather than permanent recruitment from every cohort (Laptikhovsky and Brickle 2005); this emphasizes the need for protection of high recruitment cohorts through an appropriate spatial management approach.

5. Recommendations

Data management

1. Contract observer data should be entered into the database (either the existing FIFD observer database or by creating a new database dedicated to contract observers). At the time of writing, contract observer data were available as original excel documents submitted by observers (i.e. ~16 documents per season, each with 8-10 sheets of data) and needed thorough error-proofing and better integration; establishing a database would facilitate future analyses.

2. To facilitate the matching of the observed data to e-logbook data, both FIFD and contract observers should report haul IDs assigned by the vessel, in addition to their own 'station' IDs. This would make data matching trivial, in contrast to the current practice, which is time-consuming, coding-intensive and only partially successful.

3. The option of correcting toothfish bycatch reports suspected of erroneous use of conversion factor should be discussed at FIFD and implemented if required.

Monitoring

4. The pre-season training provided to contract observers (especially for the first-timers) should be reviewed, and if necessary, updated/extended to help achieve uniform reporting practice. Feedback should be provided to the contractor (currently MRAG) on observer performance and the quality of the submitted data.

5. Vessel operators should be reminded of the correct toothfish bycatch reporting practices, i.e. when to apply conversion factor. This could potentially be done during licencing and should lead to a uniform bycatch reporting practice on the fishery side.

6. The alleged practice on some vessels of reporting toothfish bycatch by the 'box' (i.e. pooled over multiple hauls), should be discussed at FIFD.

7. The observer manual does not define whether observers are to share bycatch information with the vessels they are on; in effect, this is left to the discretion of individual observers (both FIFD and MRAG observers) and leads to a non-uniform practice. This issue should be discussed at FIFD, and the operational policy explicitly defined.

8. Direct monitoring of toothfish bycatch should be introduced to contract observer protocol. Unlike FIFD observers, contract observers are currently not required to conduct independent sampling in the factory. Instead, they rely on the vessel (crew/ factory manager) to collect toothfish; these fish are weighed by the observer, either per haul or per 'box', but the data collected in such a way should not be considered independent observer estimates.

Fishery management

9. The C-season pre-recruitment surveys can provide estimates of 0+ toothfish recruitment strength, as well as its spatial distribution, and should be included as an objective within the survey plan. When a strong cohort is detected, a small-scale spatio-temporal closure of hotspots (if any) should be considered in the following commercial season. Access to the closed area could be allowed periodically to a single vessel for exploratory purposes; in this case, increased observer monitoring of juvenile toothfish bycatch would be advisable.

10. The currently enforced move-on rule threshold for toothfish bycatch in the calamari trawl fishery (1.5% of the total catch) should be revised. Potential candidates for a new threshold could be either in absolute (100 - 200 kg of toothfish bycatch per vessel-day) or relative terms (0.5 - 1.0% of toothfish bycatch per vessel-day); these options should be discussed further at FIFD.

6. References

Arkhipkin AI, Herrera D, Lee B, Boag T, Bradley K, Cockcroft K. 2017. Cruise Report ZDLT1-01-2017: Juvenile toothfish survey. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, 34 p.

Arkhipkin AI, Laptikhovsky VV. 2010. Convergence in life-history traits in migratory deep-water squid and fish. ICES Journal of Marine Science 67, 1444-1451.

Geange SW, Rowden AA, Nicol S, Bock T, Cryer M. 2020. A Data-informed approach for identifying move-on encounter thresholds for Vulnerable Marine Ecosystem indicator taxa. Frontiers in Marine Science 7, 155.

Laptikhovsky V, Brickle P. 2005. The Patagonian toothfish fishery in Falkland Islands' waters. Fisheries Research 74, 11-23.

Laptikhovsky VV, Arkhipkin AI, Brickle P. 2006. Distribution and reproduction of the Patagonian toothfish *Dissostichus eleginoides* Smitt around the Falkland Islands. Journal of Fish Biology 68, 849-861.

Lee B, Arkhipkin A, Randhawa HS. 2021. Environmental drivers of Patagonian toothfish (*Dissostichus eleginoides*) spatial-temporal patterns during an ontogenetic migration on the Patagonian Shelf. Estuarine, Coastal and Shelf Science 259, 107473.

Lee B. 2017. Age structure for Patagonian toothfish *Dissostichus eleginoides* from Falkland Island waters: January - December 2017. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, 16 p.

Muggeo VMR. 2008. Segmented: An R package to fit regression models with broken-line relationships. R News 8/1, 20–25. https://cran.r-project.org/doc/Rnews/.

Ochoa-Quintero JM, Gardner TA, Rosa I, de Barros Ferraz SF, Sutherland WJ. 2015. Thresholds of species loss in Amazonian deforestation frontier landscapes. Conservation Biology 29, 440-451.

Randhawa HS. 2020. TOO bycatch report: a review. Efficacy of the 1.5% bycatch threshold. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, 147 p.

Robertson BP, Savage C, Gardner JP, Robertson BM, Stevens LM. 2016. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators 69, 595-605.

Skeljo F, Lee B, Winter A. 2022. 2021 Stock assessment report for Patagonian toothfish (*Dissostichus eleginoides*). Fisheries Report SA-2021-TOO. Fisheries Department, Directorate of Natural Resources, Falkland Islands Government, Stanley, Falkland Islands. 44 p.

Tilbury JB, Van Eetvelt WJ, Garibaldi JM, Curnsw JSH, Ifeachor EC. 2000. Receiver operating characteristic analysis for intelligent medical systems-a new approach for finding confidence intervals. IEEE Transactions on Biomedical Engineering 47, 952-963.

Youden WJ. 1950. Index for rating diagnostic tests. Cancer 3, 32-35.

Appendix 1.

back to text

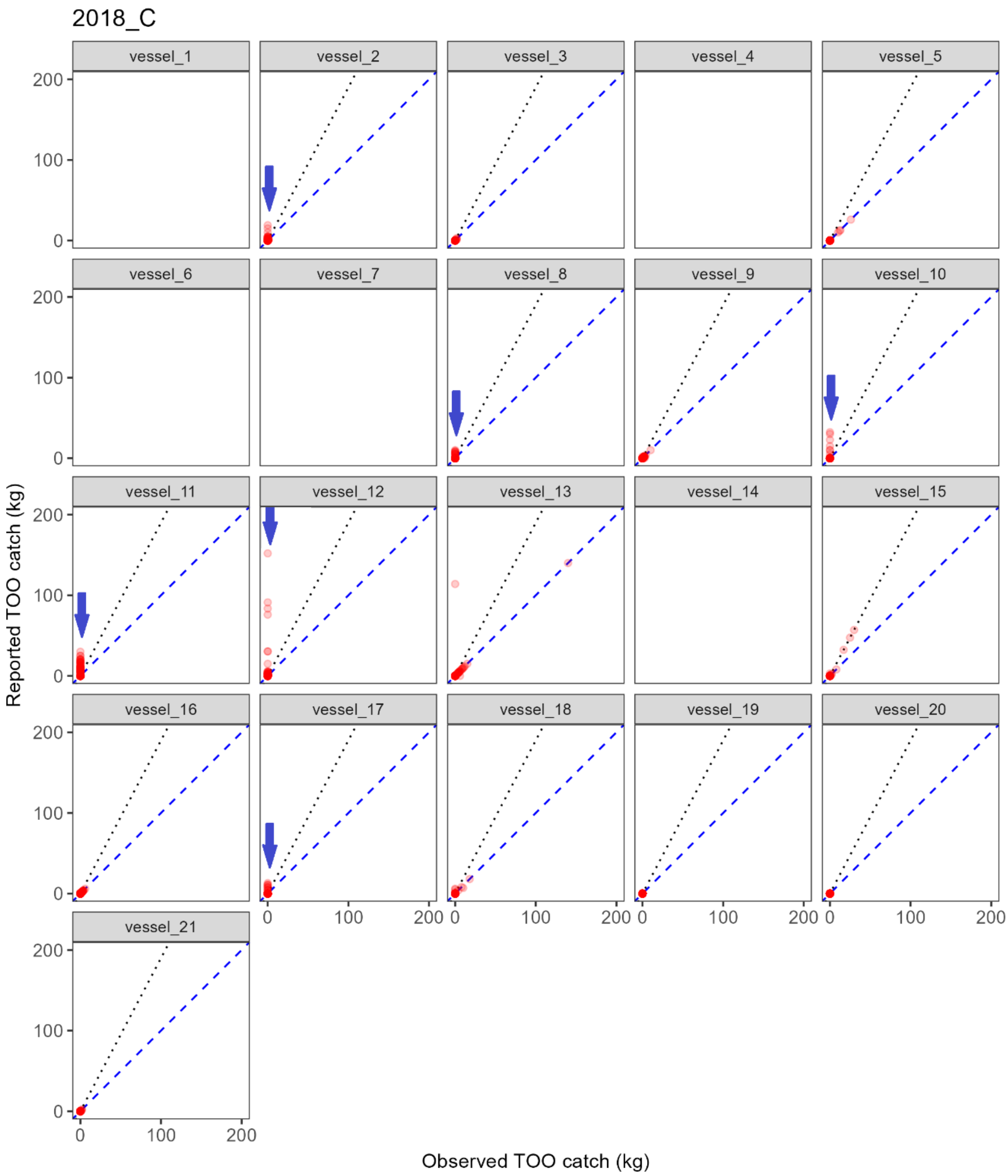

Figure A.1. Contract observer vs. reported toothfish bycatch per haul (red points), per vessel and season. Dashed blue lines denote reported = observed bycatch. Doted lines denote reported = 1.9 * observed bycatch. Blue arrows point out the data suspect of no observer monitoring. Green arrows point out the data suspect of erroneous use of conversion factor (panel 1 of 8).

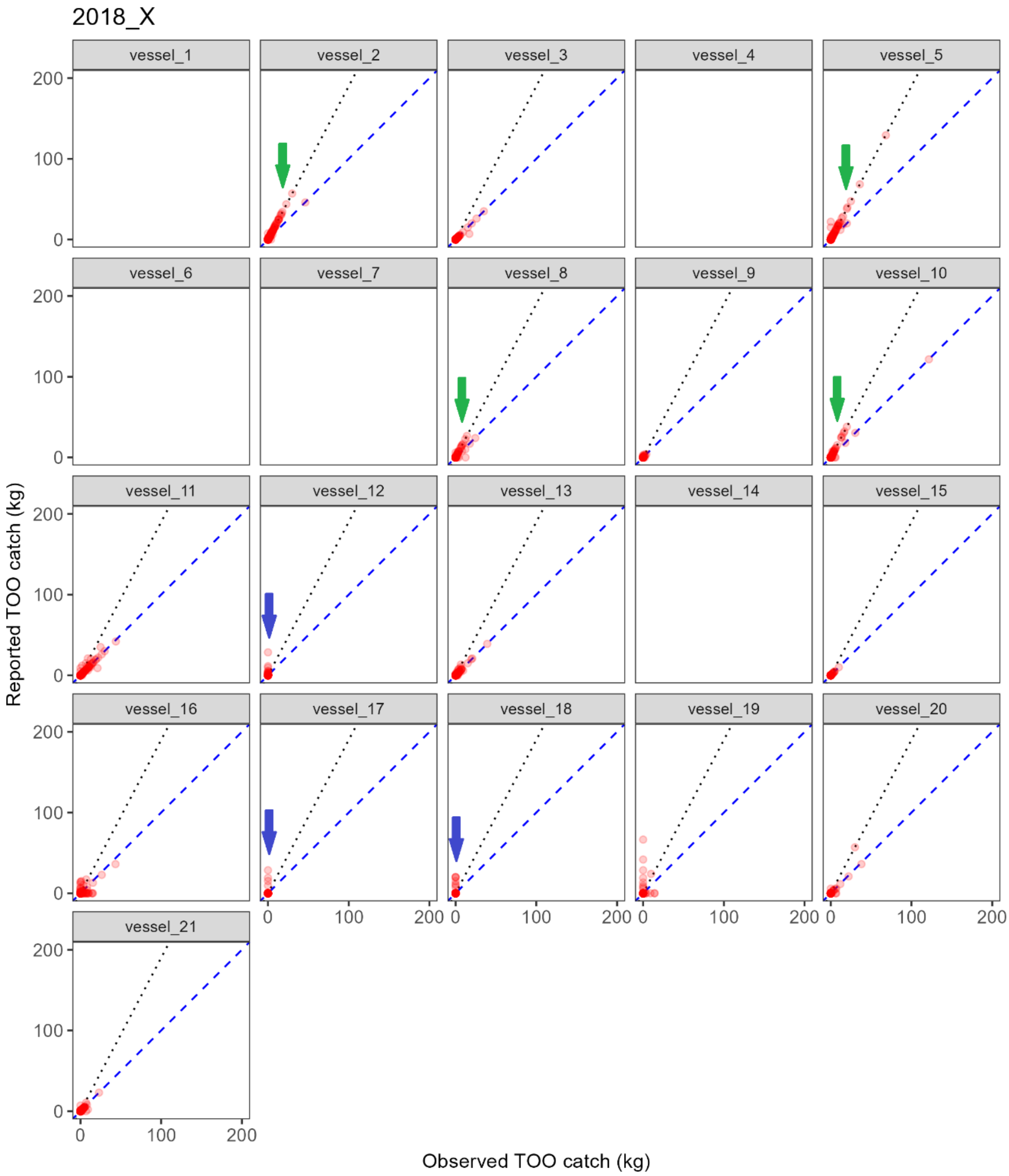

Figure A.1. Continued (panel 2 of 8).

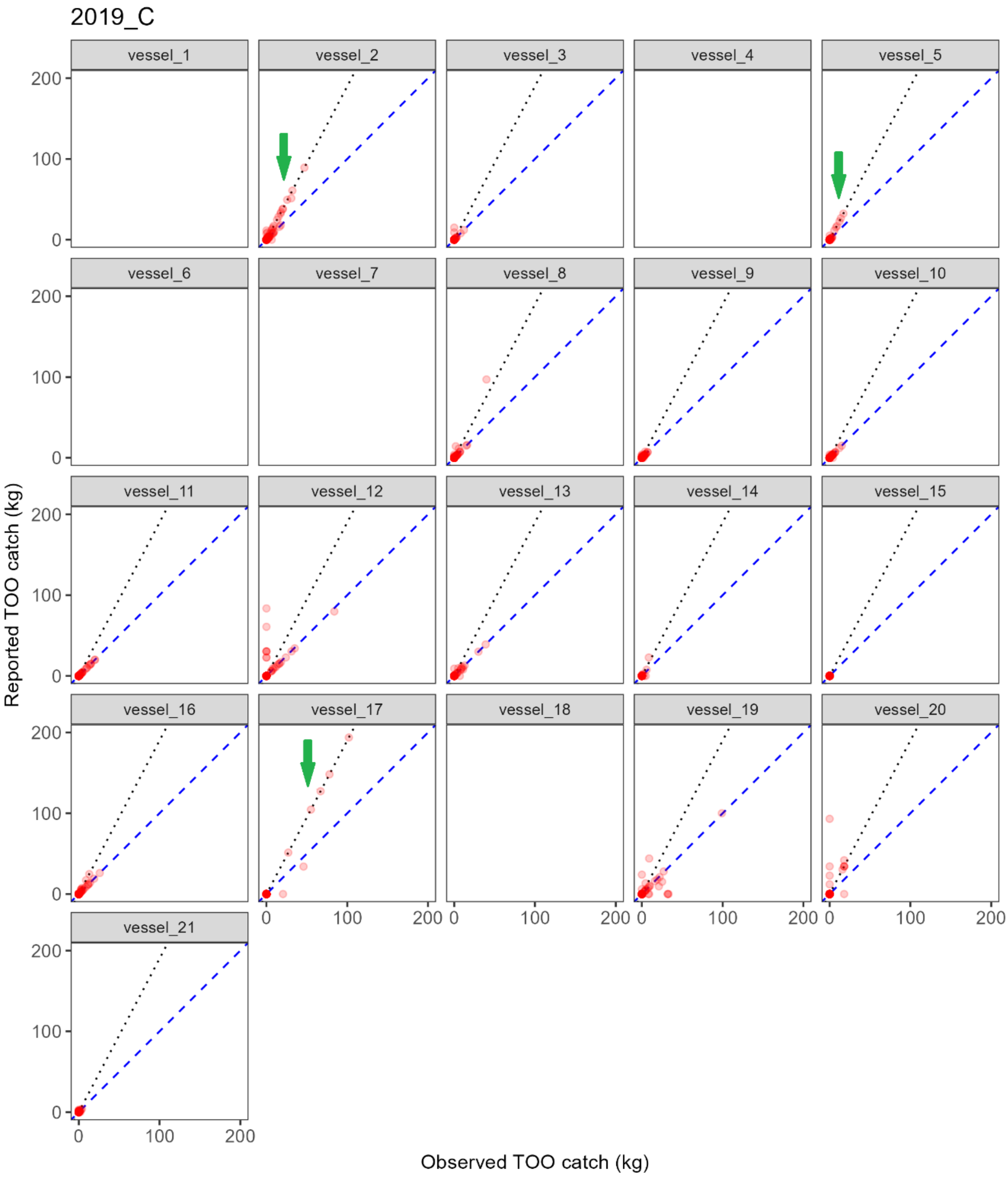

Figure A.1. Continued (panel 3 of 8).

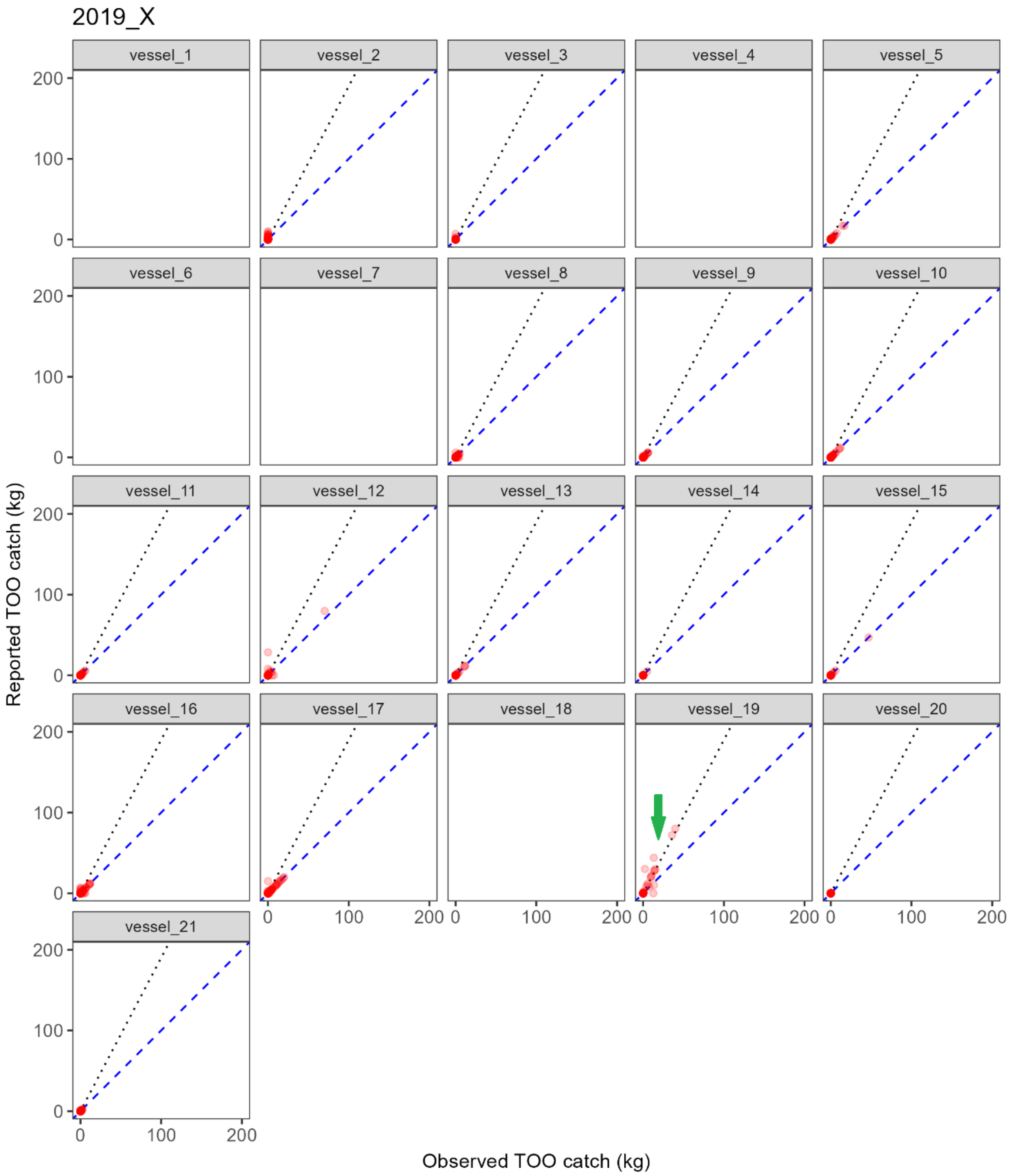

Figure A.1. Continued (panel 4 of 8).

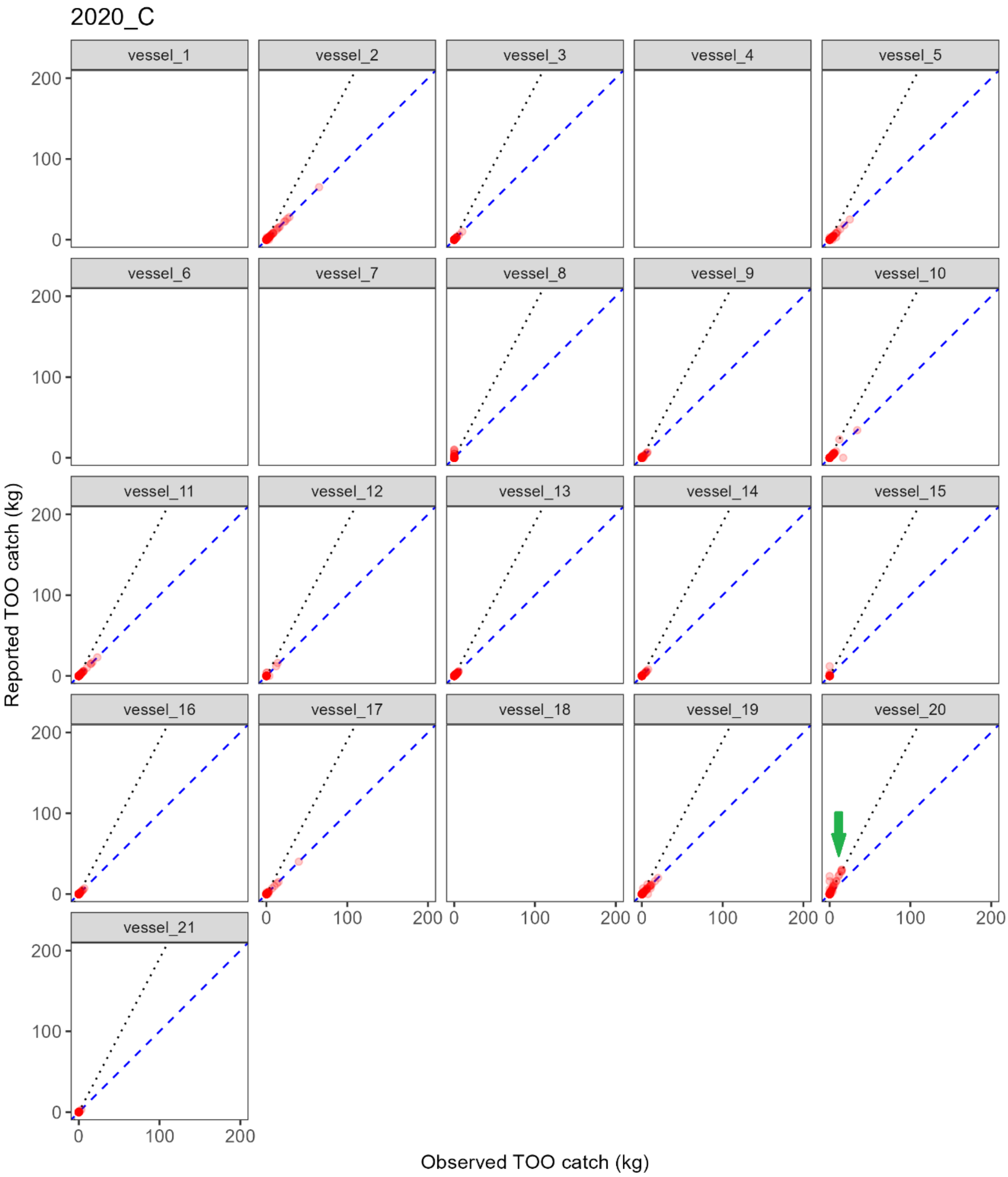

Figure A.1. Continued (panel 5 of 8).

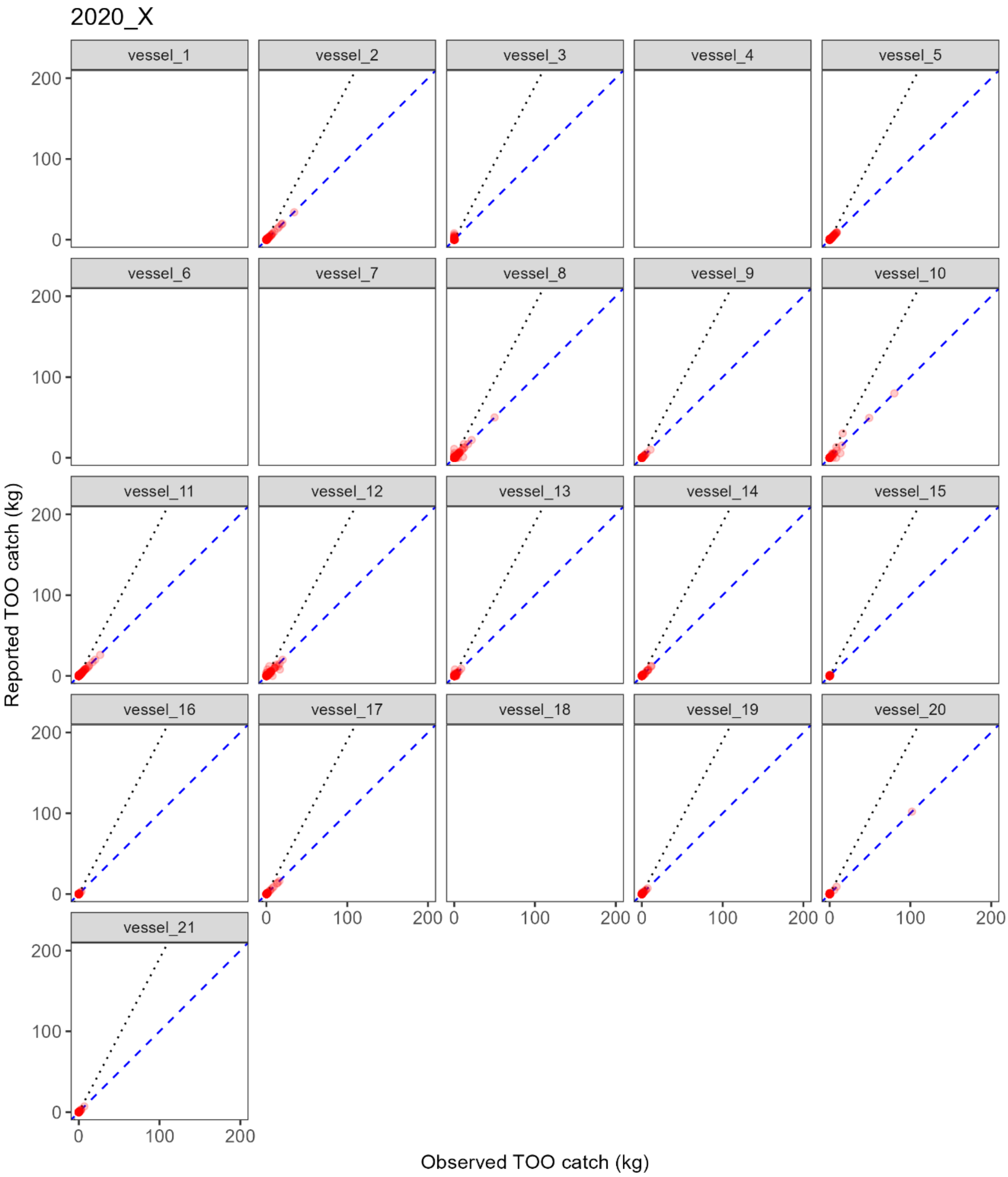

Figure A.1. Continued (panel 6 of 8).

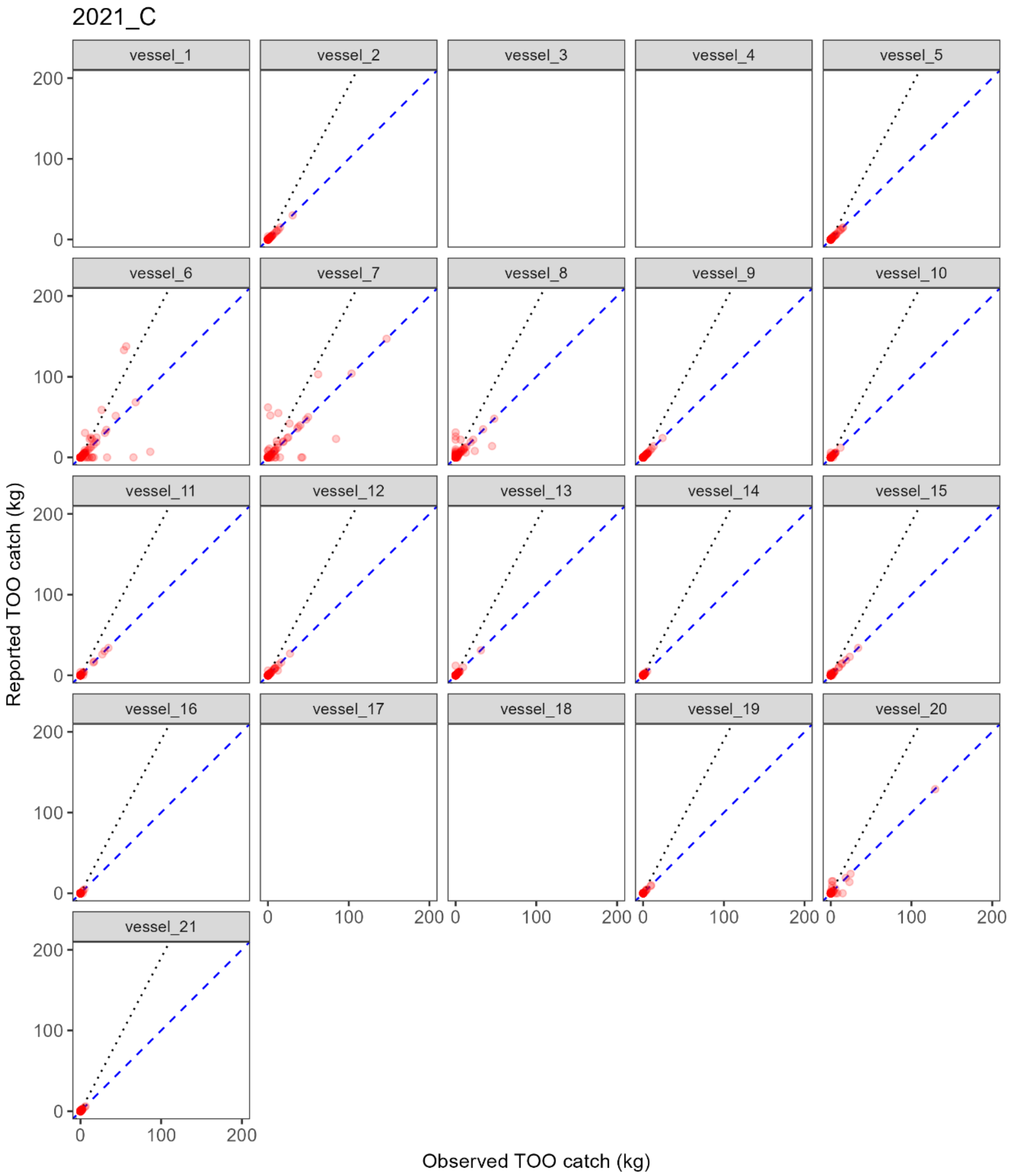

Figure A.1. Continued (panel 7 of 8).

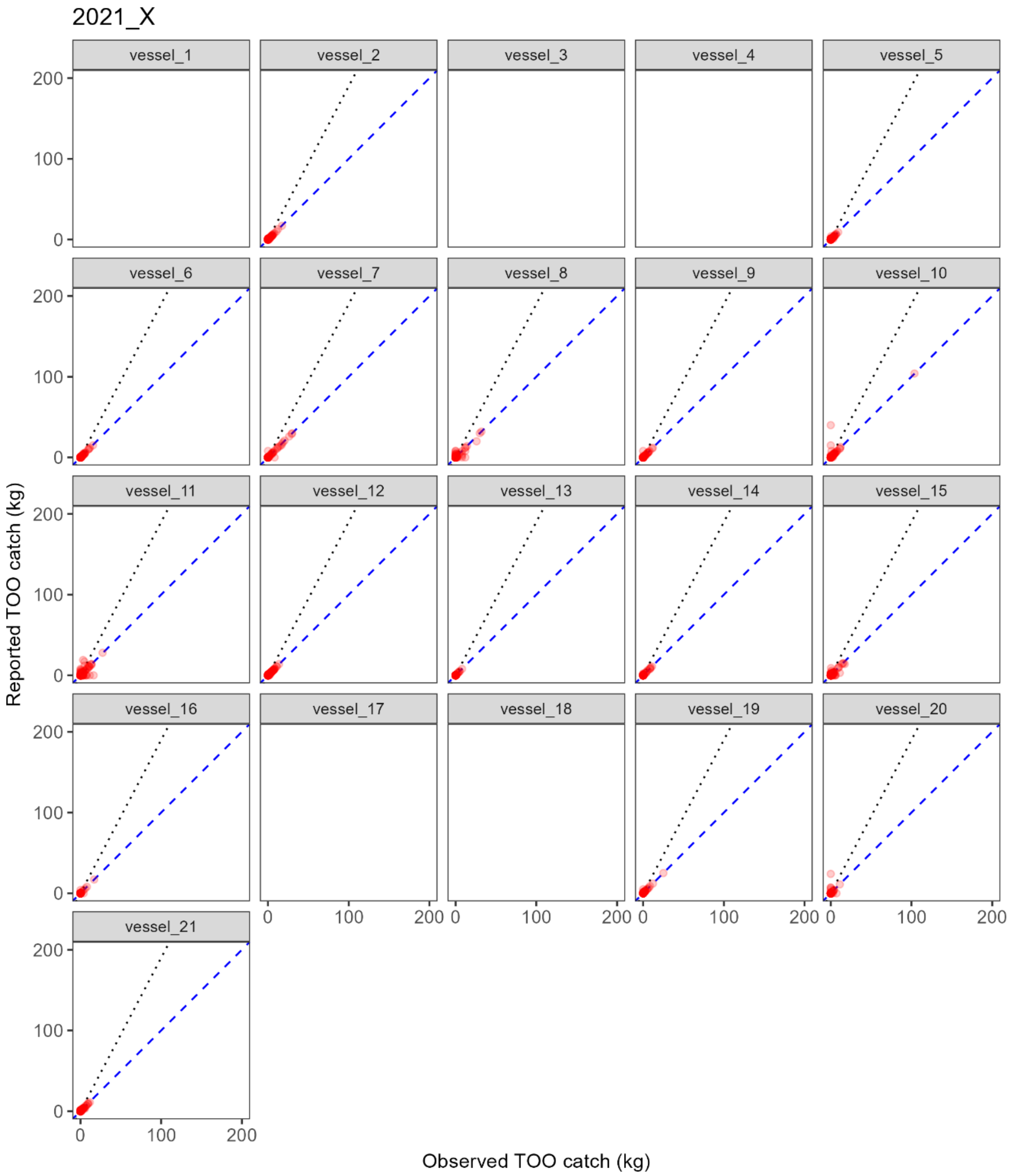

Figure A.1. Continued (panel 8 of 8).

Appendix 2.

back to text

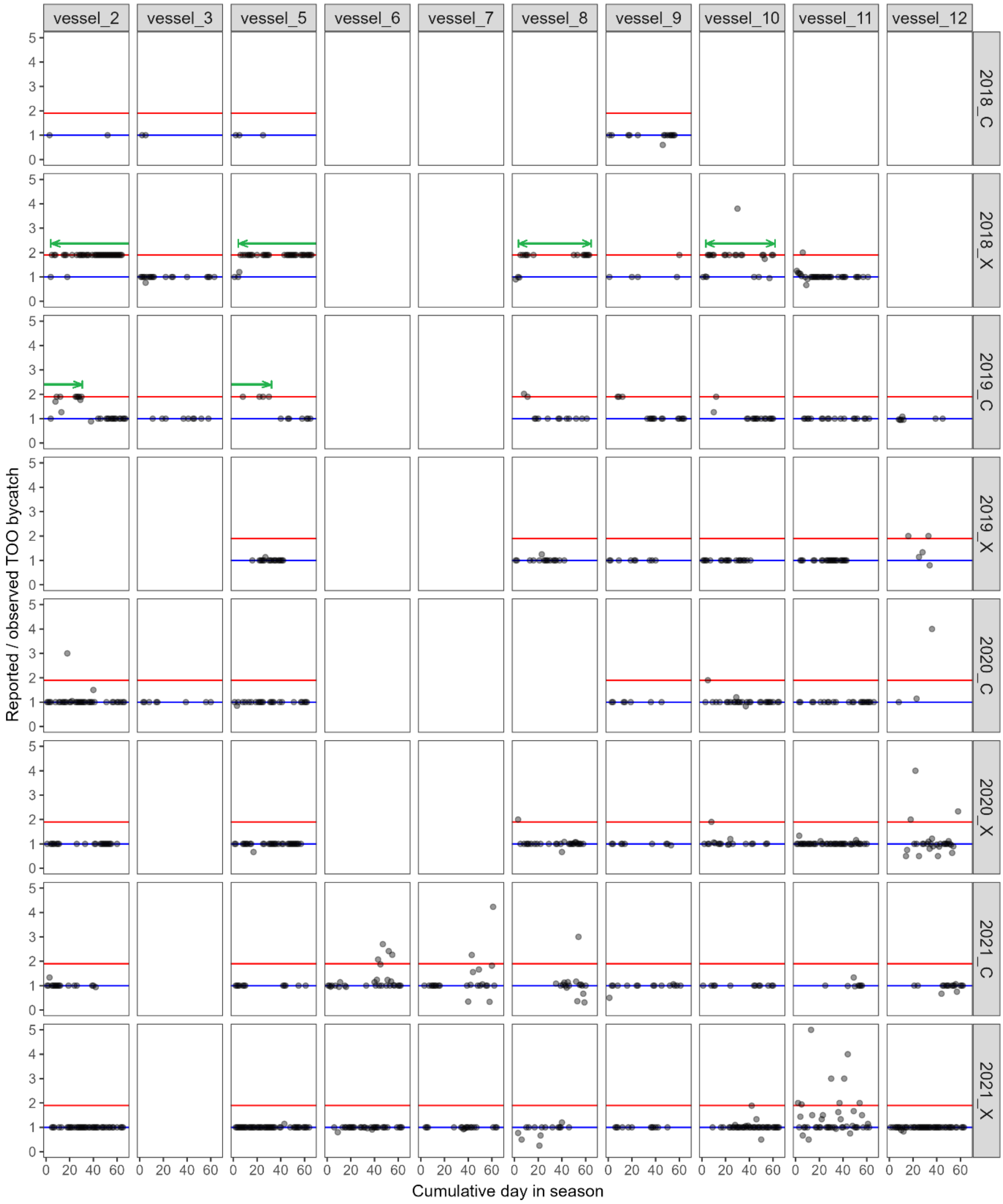

Figure A.2. Reported / observed toothfish bycatch per haul over time (black points), per vessel and season. Blue lines denote reported = observed bycatch. Red lines denote reported = 1.9 * observed bycatch. Green arrows point out periods suspect of erroneous use of conversion factor (panel 1 of 2).

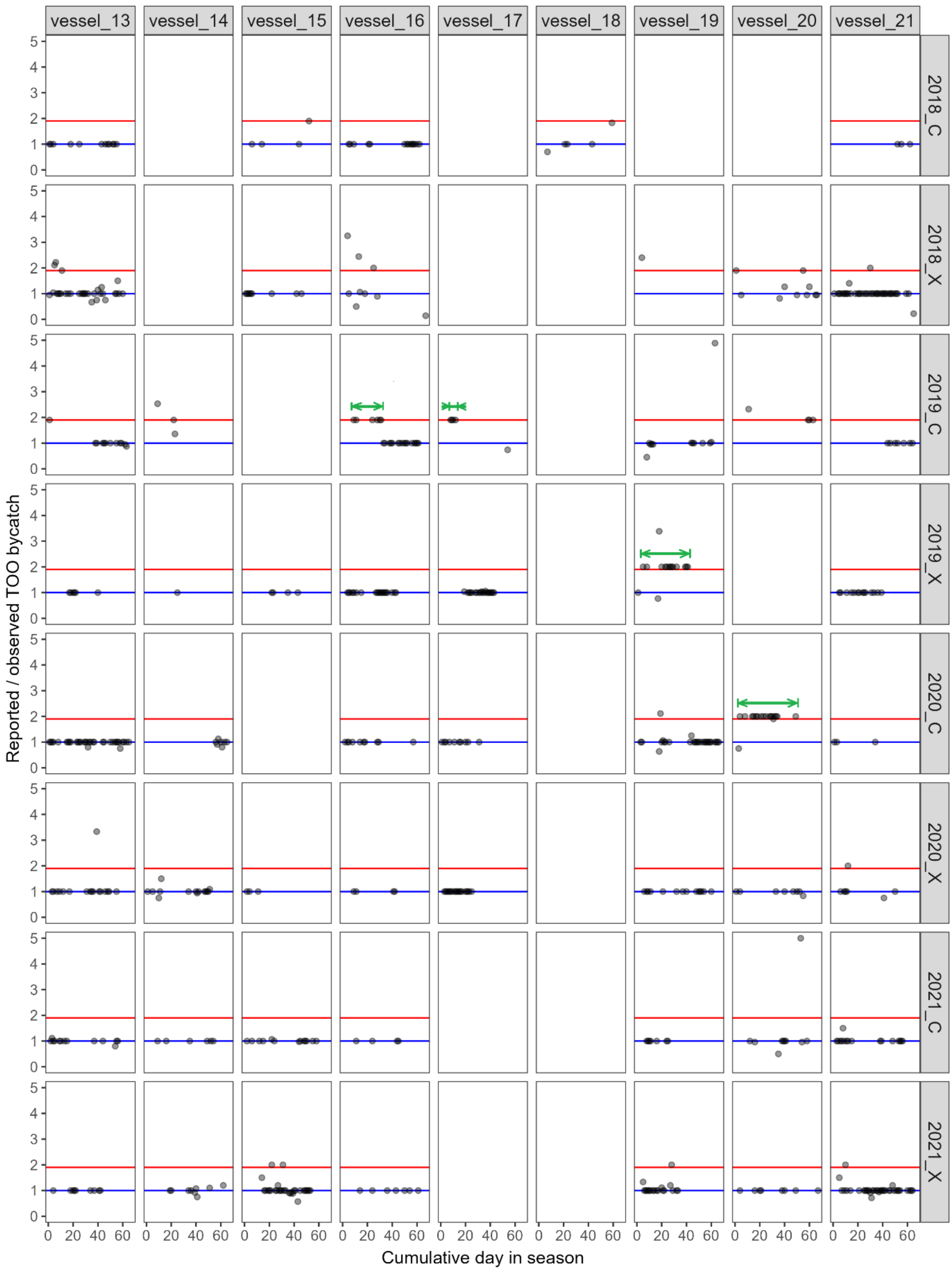

Figure A.2. Continued (panel 2 of 2).