Tuna stomachs: Is the glass half full, or half empty?

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For some of us, fishing is a bit like playing bingo: you need to be lucky, but unlike bingo, with experience and scientific knowledge you can increase your chances of winning the fishing competition or putting the catch of the day on the menu. The ongoing analysis of more than 16,000 tuna stomachs tells us more about their feeding behaviour. Looking at their fullness state under various fishing methods, we observed they had empty stomachs when caught at drifting fish aggregating devices, and fuller stomachs in free schools.

Tropical tuna ecology

Over the past 20 years, the Pacific Marine Specimen Bank has been gathering biological samples of muscles, stomachs, liver, blood, and other parts of fish caught in the Pacific Islands region and collected by fisheries observer programmes (Portal et al. 2020). Coordinated by the Fisheries, Aquaculture and Marine Ecosystems Division of the Pacific Community, we have sampled 16,396 stomachs of skipjack (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*T. obesus*) – three of the main tuna species targeted and caught in the western and central Pacific Ocean. Among these stomachs, which continue to rise in number, 8089 have been examined at the Pacific Community's fisheries laboratory in New Caledonia (Fig. 1).

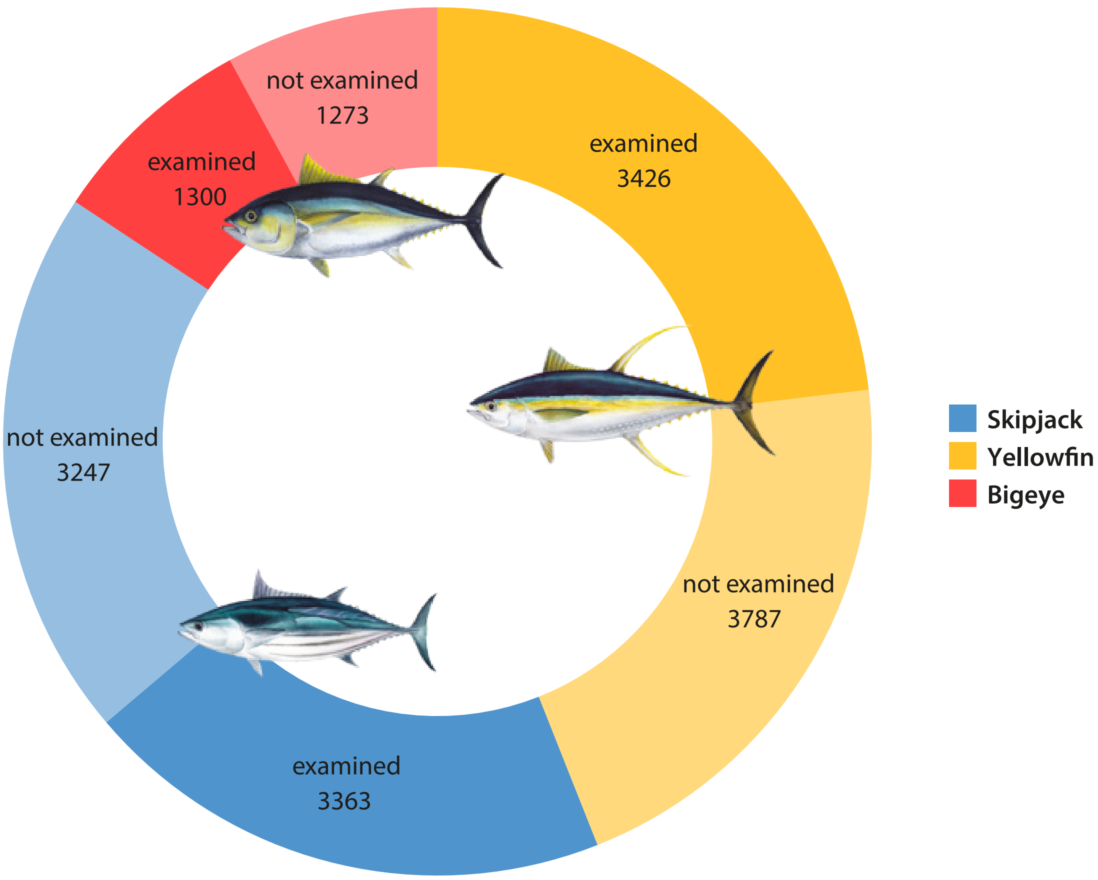

Figure 1. Summary of tuna stomachs sampled and examined.

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The foraging behaviours of top-level marine predators such as tunas provide considerable knowledge about the dynamics of the pelagic ecosystem, including food web structure, based on predator-prey distributions and how fishing or climate change is impacting this system.

The diet of tunas is linked to each individual's behaviour, habitat use, energy supply and interactions between other tunas and other species. The more we understand why the diet of large pelagic predators varies, the better we can monitor the ecosystems they are part of and manage the fisheries.

The examination of tuna stomach contents allows us to characterise their diet directly. It is a good way to look at what they have eaten at a given time, and to study the trophic interactions between species and changes that may occur over time and space (Machful and Allain 2018). For this study, SPC's FEMA team (Fisheries Ecosystem Monitoring and Analysis) wanted to quantify ingested food.

Analysis of tuna stomachs

In the laboratory, stomach samples are weighed before being opened. If baitfish were used during fishing operations, and recorded in the fishing logbook for proper identification, they are removed from the stomach content samples studied. A qualitative estimation method that visually classifies fullness into one of five categories is used to determine how much is in the fish's stomach (0 = empty, 1 = less than half full, 2 = half full, 3 = more than half full, 4 = full). This "fullness coefficient" represents the quantity (volume) of prey in the tuna's stomach. Prey species are then identified, measured and weighed. The final step of the examination is to weigh the stomach wall without prey, which allows the total weight of the stomach contents to be deduced.

Many of the stomachs examined were empty or near empty at the time the fish was captured. This is most apparent in skipjack tunas, for which 46% of all stomachs analysed were empty, while empty stomachs represented only 16% and 33% for yellowfin and bigeye tunas, respectively (Fig. 2). But why are they empty? What factors influence the success of tuna feeding? What makes some tuna feed less than others?

Choosing the most appropriate fullness index

Several approaches are used to describe the diet of fish, and are divided into qualitative and quantitative methods, all with varying degrees of bias. Here, we aim to focus on "stomach fullness" because it is a useful index to quantify ingested food, and is often used by scientists in trophic studies (Hyslop 1980; Chipps and Garvey 2006).

An accurate index of stomach fullness provides information that complements other data we collect on which prey species are on the menu and how abundant they are. It can also help answer ecological questions on the foraging efficiency of tunas, and gives information on individuals' dietary choices by telling us whether stomach fullness varies, for example, according to size and species (do they eat the same way?). Such an index also allows an understanding of the many ecological processes at the community-scale, such as how fish behave during a fishing operation (are they hungry when caught?), or to study the cohesion of fish according to the association of schools (why and how do they group together?).

As a first step to study the stomach fullness of a fish, it is possible to use the fullness coefficient qualitative estimation method, determined during stomach examination, which is simple, easy and quick to apply. However, this has been criticised by scientists because of its potential subjectivity (Hynes 1950) because it depends on the experience and judgment of the person performing the examination. Because the stomach is a muscle that can expand, some examined stomachs presented a very thin wall while others were very thick with clearly visible pleats, which means they were not expanded. Therefore, the perception of fullness can often be biased (Fig. 3). It can be considered a useful index but has some limitations. For example, it is a practical tool for fisheries observers because it allows them to assess stomach fullness at sea.

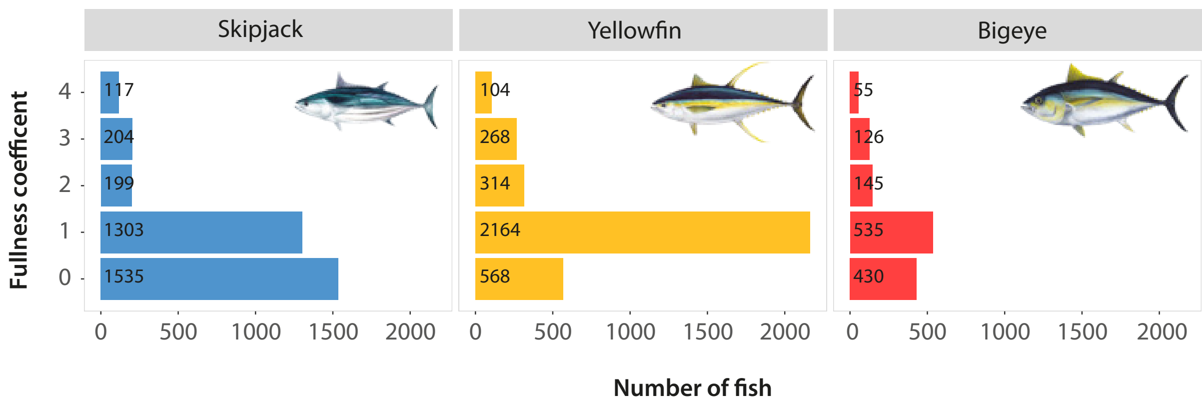

Figure 2. Distribution of the fullness coefficient by species.

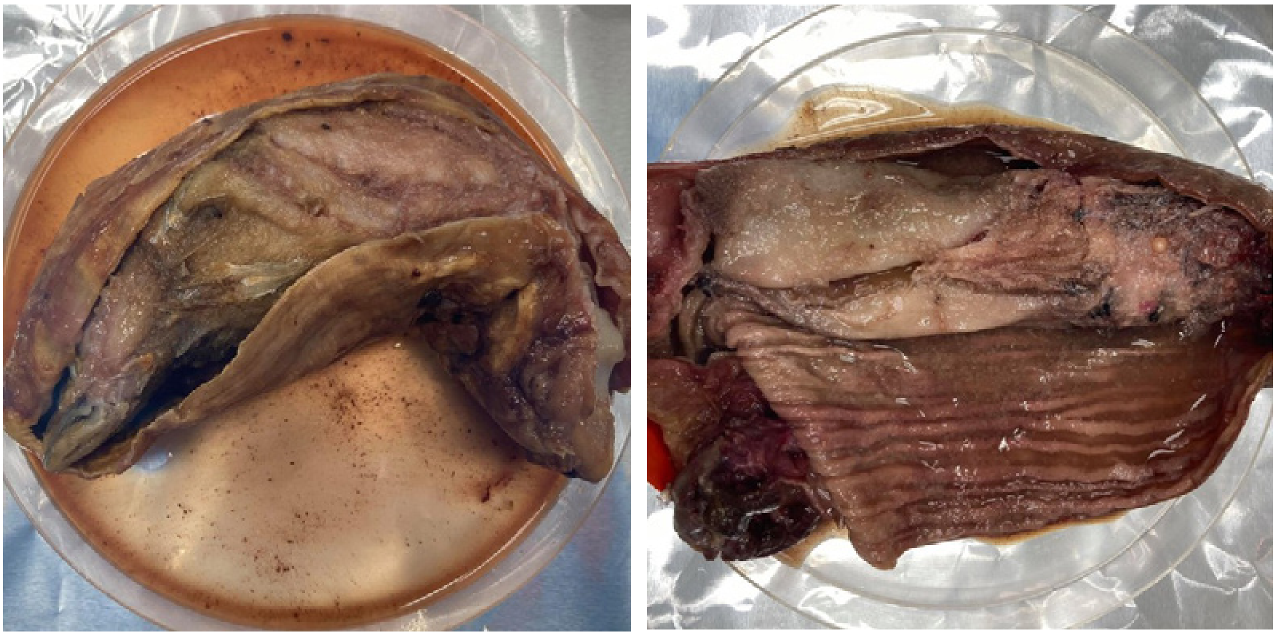

Figure 3. Two stomachs with different wall thicknesses: thin and stretched on the left, and thick with pleats on the right).

To minimise subjectivity, we use the gastrosomatic relationship (GSR) (Herbold 1986) by calculating the ratio between the observed weight of the food or prey in the stomach (prey weight) and the fish's body mass (weight):

GSR = prey weight / fish weight

However, fish weight can vary, for example, with the reproduction period, creating a bias in the GSR, thus making it impossible to compare values through time. Moreover, it is impossible to compare GSR values between tuna species. To avoid these problems, we have begun using a new, standardised fullness metric, which is more robust and comparable between time and species, but above all, that can directly capture the fullness itself. The fullness metric we propose takes into account the length of the fish, and the maximum capacity of the stomach (when full). We have, therefore, applied the following formula first proposed by Herbold in 1986:

FM = prey weight / predicted max. prey weight

Where again: prey weight is the observed weight of prey in the stomach and predicted max. prey weight is the predicted maximum weight of prey for a fish of a given length. The predicted maximum weight of prey at length was calculated using a log-log regression between the maximum stomach content weight observed (using only the 277 full stomachs, with a fullness coefficient of 4, Fig. 2) and fish length from our database.

We have chosen to use the new fullness metric for further inference in our analyses because it provides a more quantitative measure of stomach fullness than the fullness coefficient, and can be compared for fish of all sizes. The fullness metric values range from 0 to 5, with zero representing an empty stomach, and maximum values representing the fullest stomachs (Fig. 4).

Effects of covariates of interest

This alternative fullness metric is being used to understand what could potentially drive stomach fullness in tunas. Through this work, we are exploring the effects of ecological, fishery-related and environmental factors for each of the three tuna species.

We fitted a series of generalised linear models to the fullness metric of tuna to better visualise the effect of each factor before combining them all into one model. We describe these results in detail for skipjack below, with a summary for yellowfin and bigeye tuna.

Results for skipjack

Effects of fishing gear

For the model, fishing gear is a significant factor contributing to the variations in stomach fullness of the tunas. Skipjack were caught mostly by pole-and-line and purse-seine methods. These tunas have fuller stomachs when caught by pole-and-line, and emptier stomachs when caught by purse-seine gear, with a significant difference between these two gear types (Fig. 5). If we look at longline gear, the mean is similar to pole-and-line, but with a greater variability. The wide confidence intervals for handline gear may be due to the small amount of data for this gear type. Each fishing gear has different sampling methods, which would explain the differences in values. It may also be related to a number of other factors, including the type of fish schools targeted by the fisheries.

Effects of fish school association

Tropical tunas tend to aggregate around floating objects, and this is why fisheries target fish aggregating devices (FADs) and other structures associated with fish schools (e.g. logs, seamounts). The model predicts a significant relationship between the stomach fullness and this parameter.

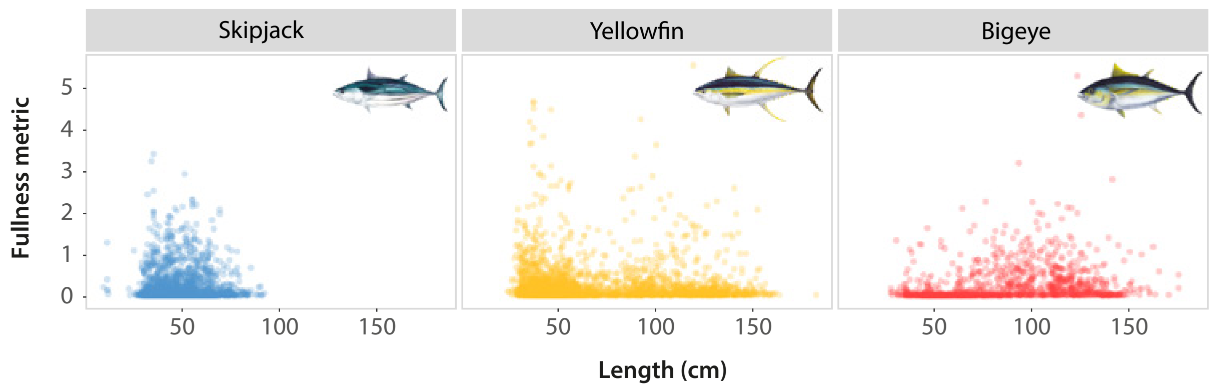

Figure 4. Distribution of the fullness metric by species and size.

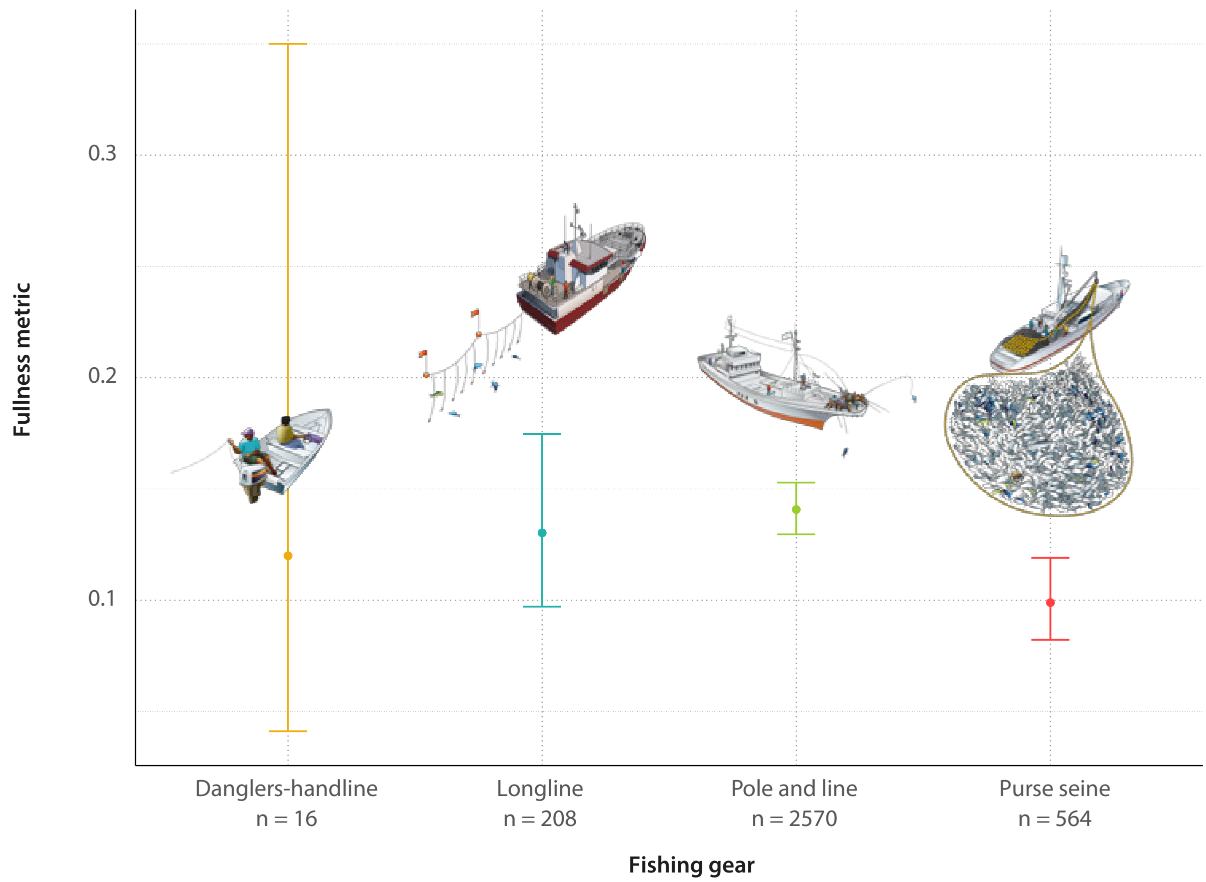

Figure 5. Predicted average of fullness metric and 95% confidence intervals for each fishing gear type (n = number of observations).

Skipjack were caught mostly around anchored FADs and in free schools (Fig. 6). Stomachs are fuller when these tunas are in free schools and around seamounts. But seamounts show greater variability, perhaps due to the paucity of data. These two school types were mostly targeted by pole-and-line gear. Stomachs are clearly fuller in free schools than when associated with anchored FADs, drifting FADs and logs. The FAD effect on stomach fullness has already been demonstrated by other authors and it may be due to a depletion of locally available prey at the FADs by the aggregated predators (Buckley and Miller 1994; Menard et al. 2000). Stomachs are emptier at drifting FADs – the school association that purse-seine vessels target the most. In addition to fishing methods and prey availability, differences in results between fish school associations may be due to location (e.g. close to or far away a coastline).

Effects of time of the day

The time of the day at which an individual tuna was caught was also examined for its effect on the stomach fullness metric. Fish caught early in the morning, as is often the case with associated schools, were very likely to have empty or near empty stomachs, while stomachs were more likely to be full later in the day (Fig. 7).

Effect of sea surface temperature

We also tested a model with the sea surface temperature anomaly. The model indicates that sea surface temperature influences stomach fullness, and stomachs are predicted to be fuller when the sea surface temperature is warmer than usual (Fig. 8). This may be related to seasonal movements of water masses, such as when the warm pool expands during El Niño events and allows skipjack to access different areas and, therefore, new prey species.

Results for yellowfin and bigeye tunas

The same analysis was undertaken for yellowfin and bigeye tunas. The results show similar trends but with some differences for each species. Some averages of the fullness metric are higher for these two species and there is more variability. Tunas always seem to feed better when they are in free schools and caught by longline, possibly because they may be actively hunting when they are targeted by this fishing

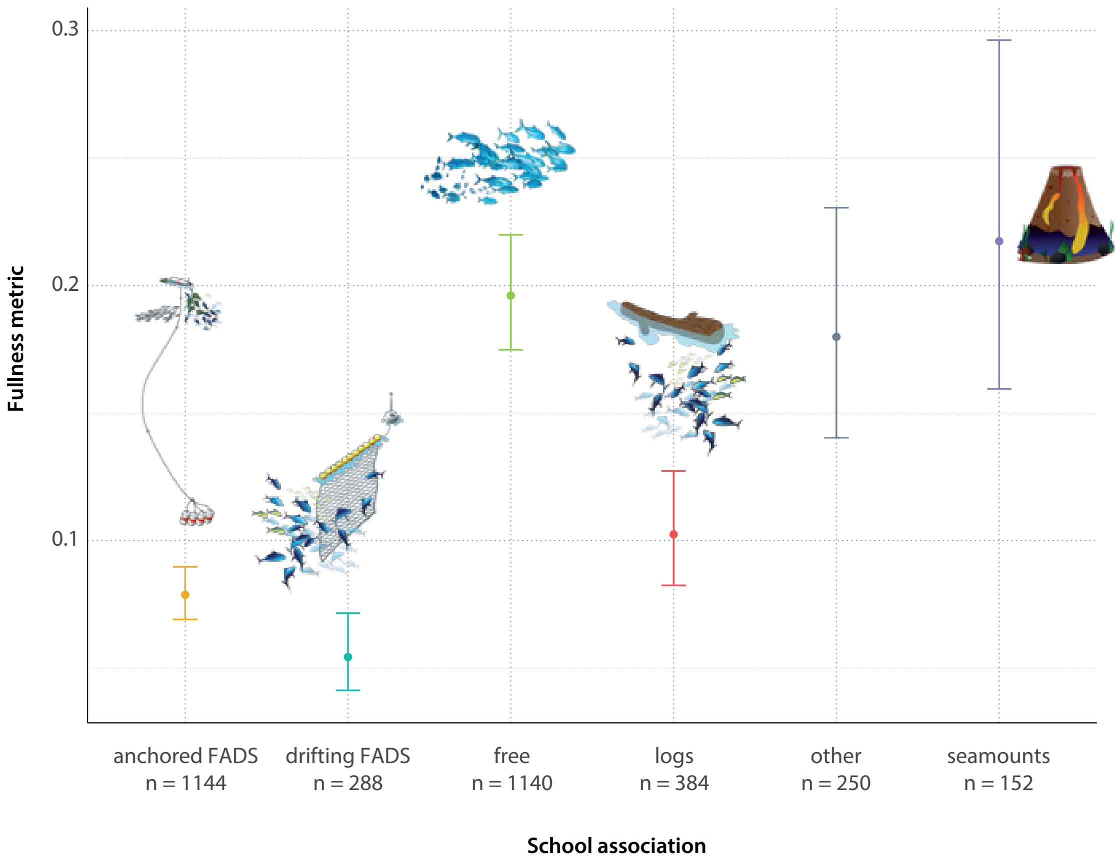

Figure 6. Predicted averages of fullness metric and 95% confidence intervals for each fish school association (n = number of observations).

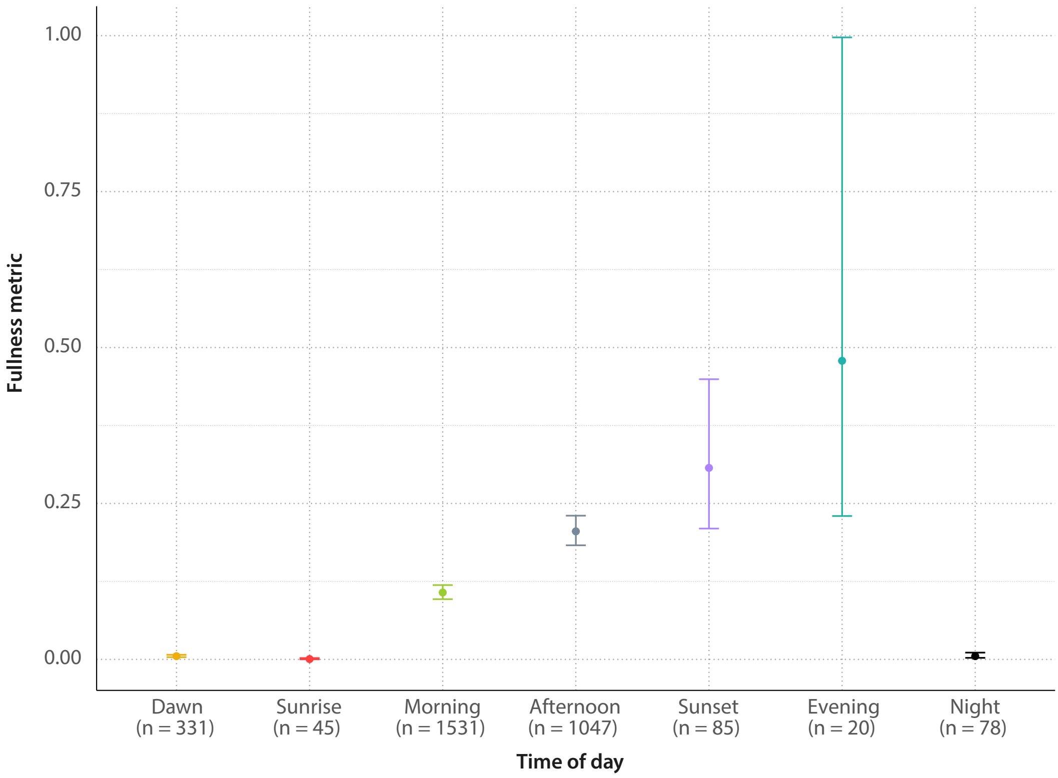

Figure 7. Predicted averages of fullness metric and 95% confidence intervals for different periods of the day (n = number of observations).

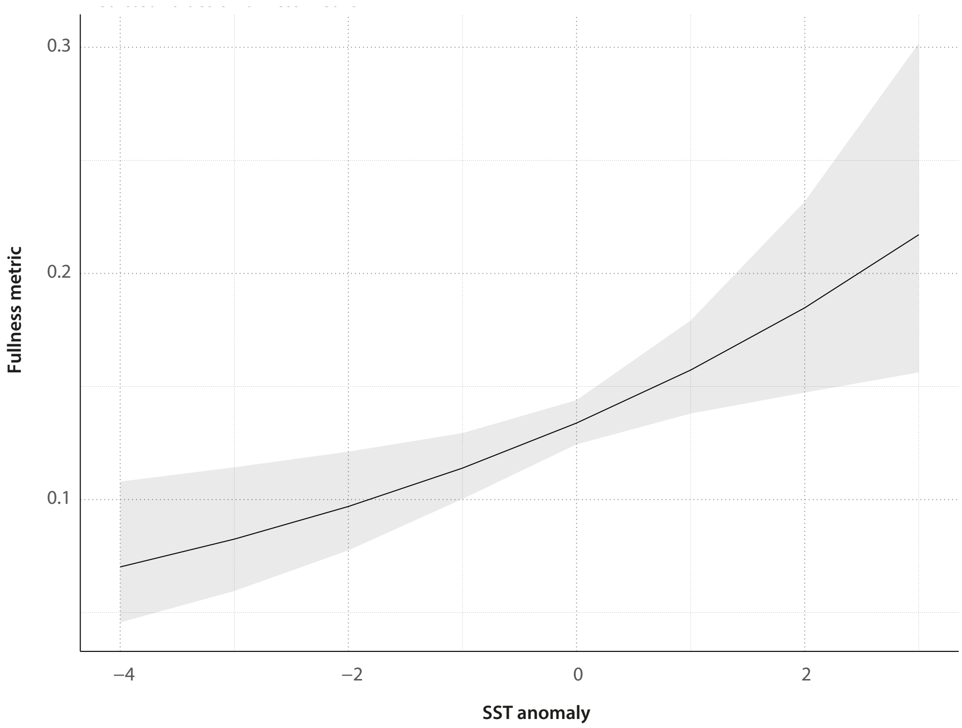

Figure 8. Predicted averages of fullness metric and 95% confidence intervals for the sea surface temperature anomaly (in degrees Celsius).

gear type. As with skipjack, these two species also have a fuller stomach when the sea surface temperature is higher than usual.

Further work

The fullness metric is useful to study the diet of tunas, and these preliminary results allow us to conclude that feeding success varies with differing degrees, depending on the species and other factors. Analyses continue as we still need to test additional ecological parameters and generalised models to further investigate the results and understand if strong changes in, or impacts on, tuna feeding success may have occurred in the western and central Pacific Ocean.

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