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Stomach content and stable isotope analysis of sailfish (*Istiophorus platypterus*) diet in eastern Taiwan waters

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ABSTRACT

Stomach content analysis (SCA) and stable isotope analysis (SIA), coupled with isotopic-mixing model analysis, were used to estimate diet composition of sailfish *Istiophorus platypterus* in eastern Taiwan waters. SCA provided information on diet, but the high occurrence of empty stomachs (48.5%) limited this analysis. According to the index of relative importance (%IRI), the most important prey items were *Priacanthus macracanthus* (38.7%), followed by *Auxis* spp. (35.9%), and *Trichiurus lepturus* (8.5%). However, the most important prey groups for adult sailfish (>181 cm, LJFL) as estimated by the stable isotope-mixing model were *T. lepturus* (32.6%), *Katsuwonus pelamis* (15.8%), and *P. macracanthus* (11.3%), and for maturing sailfish were *K. pelamis* (12.9%), *P. macracanthus* (10.4%), and *T. lepturus* (32.6%), respectively. Juvenile sailfish feed primarily on smaller prey items with lower $\delta^{15}N$ values, while adult sailfish preferred larger prey items with higher $\delta^{15}N$ values. Our findings suggested that an integrated SCA and SIA is considerably more powerful than using SCA alone in determining diet composition of sailfish over long time scales. In summary, a high diversity in the diet composition of sailfish was found and included an array of coastal, benthic, pelagic, and mesopelagic species. Sailfish are most likely opportunistic feeders consuming the most abundant prey items in eastern Taiwan waters.

1. Introduction

Sailfish *Istiophorus platypterus* (Shaw and Nodder, 1792) are apex predators in pelagic ecosystems (Kitchell et al., 2006), and are distributed in tropical and temperate waters worldwide (Nakamura, 1985). Sailfish are opportunistic foragers (Rosas-Alayola et al., 2002) and the abundance, diversity and distribution of prey items changes in different foraging habitats. In the western Pacific near the Kuroshio Current, sailfish spawn around eastern Taiwan (Chiang et al., 2006a,b) and are seasonally abundant to local fisheries from April to October, with a peak from May to July. They are primarily targeted with gill nets, set nets, and harpoon fleet and are also retained by inshore pelagic longline fisheries (Chiang et al., 2004). Sailfish has a high economic value and is ecologically importance in eastern Taiwan. For the past decade, the annual landings of sailfish in Taiwan fluctuated between 500 and 1000 mt, with 80% captured off the eastern coast. Although sailfish are an important resource for the local fishery, there are few reports about their diet composition in the western Pacific.

Any reductions in the abundance of top predators have the potential to alter food web dynamics and trophic structure in marine systems (Paine, 1966; Hinke et al., 2004), while changes in the prey community can also affect top predators (Rosen and Trites, 2000). Trophic studies are essential to ecosystem analyses to infer biological niche overlap, suitable habitat, and level of fisheries interactions (Lopez et al., 2010). Determining trophic interactions between species is a major step toward a better understanding of the ecosystem dynamics.

Stomach content analysis (SCA) is the most widely used method in tropho-dynamics to gauge niche overlap and to construct food webs, although it can be biased by opportunistic feeding and different digestion rates of prey. However, SCA can provide detailed information on diet composition, prey size, distribution, consumption rates and foraging habitats over short timescales (Chipps and Garvey, 2007). Stable isotope analysis (SIA) tracks diet over longer timescales, but is dependent on tissue turnover rates (Gannes et al.,

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1998). The analyses of natural biological tracers, such as the stable isotope ratios of carbon (δ^{13}C) and nitrogen (δ^{15}N), are often employed for trophic ecology studies, to trace energy flow pathways through food webs (Cabana and Rasmussen, 1996; Post, 2002). The δ^{15}N value of a predator, when compared with the trophic level of a primary consumer, provides a general and integrated view of the trophic position at which the species feeds, although it does not stipulate specific dietary information (Post, 2002).

Though the food habits of sailfish have been documented from the analysis of stomach contents in Mexico and the eastern Pacific (Rosas-Alayola et al., 2002; Arizmendi-Rodríguez et al., 2006), comparable information in the western Pacific is lacking. A previous study by Tsai et al. (2014) was conducted in Taiwan using stable isotopes and found that body size of sailfish was significantly correlated with δ^{15}N values, which indicated a presumed shift in diet and trophic position through different size-classes. However, the relationship between sailfish and their prey still needs further exploration. To estimate diet composition of sailfish, we investigated food and feeding ecology of sailfish by stomach content and stable isotope analyses. Linear mixing models using multiple sources and two isotopes incorporating a Bayesian framework (Parnell et al., 2010) were applied to estimate diet composition for juvenile, maturing and adult sailfish and extend the study of Tsai et al. (2014). This additional information in turn can be used to estimate food consumption rates and biomass of different prey groups eaten by sailfish. Moreover, predator-prey relationships and energy flow can be quantified in order to assess the impact of resources in the community, which can be subsequently used for ecosystem-based management.

2. Materials and methods

2.1. Data collection and samplings

Sailfish specimens were caught by commercial fisheries (i.e., harpoon, longline, gillnet and set nets), between August 2009 and August 2012 off eastern Taiwan (∼20°20′–23°40′ N, and ∼120°40′–123°20′ E) (Fig. 1). The whole weight of each specimen was weighed to the nearest kg and the lower jaw fork length (LJFL) was measured to the nearest cm at the Shinkang fish market. After measuring length and weight, sailfish samples were brought to the Eastern Marine Biology Research Center, Fisheries Research Institute, located nearby the Shinkang fish market, for further analysis.

2.2. Stomach content analysis

A total of 505 stomachs of sailfish specimens collected at Shinkang fish market were used for SCA. Sailfish were caught by inshore commercial fisheries and refrigerated immediately with ice on board to keep freshness of body. We obtained these sailfish samples after competitive bidding and stomachs were removed for analysis at the laboratory. Each stomach was cut open, and contents were washed through a 1-mm mesh size sieve. Identification on taxa was carried out to the lowest possible taxonomic level. Wet weight and fork length (FL) of prey items were measured to the nearest g and cm, respectively. Taxonomic level based on published guides and online keys (Froese et al., 2013; Shao, 2014).

Diet was analyzed by calculating three diet indices for each prey taxon: (1) percentage by wet weight (%W), (2) percentage by number (%N), and (3) frequency of occurrence (%FO). For quantitative analysis of gastric contents, the index of relative importance (IRI) was calculated to represent the most important prey items (Pinkas et al., 1971; Cortés, 1997) as a percentage relative to the diet composition by the following equation:

$$\mathrm{IRI} = (\%W + \%N) \times \%\mathrm{FO} \quad (1)$$

To readily allow comparison among prey items, the IRI was standardized to %IRI for each prey item (Cortés, 1997). All identifiable prey items were aggregated into 14 taxonomic categories for analysis and interpretation based on relative importance and abundance. Fish prey species were pooled as 13 groups: *Auxis* spp., *Priacanthus macracanthus*, *Trichiurus lepturus*, *Decapterus* spp., *Mene maculate*, *Scomber japonicus*, *Katsuwonus pelamis*, Exocoetidae, Belonidae, Gempylidae, Clupeidae, Tetraodontidae, and Bramidae. Cephalopods were categorized together as a separate group (Table 1). Minor fish prey families, unidentified fish or invertebrates and debris were grouped together into an "others" category. To remove the bias relating to overestimation of squid beaks or other identifiable hard parts which are not digestible, only undigested and partially digested prey items were used for the analysis, and stomachs with prey in the nearly digested state were regarded as empty (Shimose et al., 2006).

2.3. Stable isotope analysis

According to a previous reproductive (Chiang et al., 2006a) and a stable isotope studies (Tsai et al., 2014); 50% of sailfish reached sexual maturity at ∼166 cm (LJFL) and stable isotope values were also reported to significantly shift ($P < 0.001$) over the size range 161–180 cm (LJFL). Therefore, to examine whether there was a shift in diet between different life stages, we collected sailfish samples and pooled them into three groups; juvenile sailfish (<140 cm), maturing sailfish (141–180 cm) and adult sailfish (>181 cm, LJFL). A stable isotope mixed model analysis was used to examine the diet composition in different life-history stages (Parnell et al., 2010).

White muscle tissue samples (∼1 cm^3) of 31 juvenile sailfish, 41 maturing sailfish and 33 adult sailfish, were examined for SIA (Table 2). Muscle samples from 2 to 9 specimens of each of the 14 prey items (Table 2) were taken to predict sailfish diet composition using SIA and stable isotope mixing model analysis (Varela et al., 2013). Muscle tissue below the dorsal fin was usually taken for fish and sections of mantle were collected from cephalopods (Revill et al., 2009).

Sailfish and prey sampled tissues were frozen at −80 °C until processing. Dissected tissues were acidified (10% HCl) to remove any residual carbonates, rinsed with distilled water and were freeze-dried for approximately 48 h. Stable isotopes were determined for sailfish and their prey following Davenport and Bax (2002) and Tsai et al. (2014). To standardize isotope measurement, isotopic values were expressed in parts per thousand (‰) as deviations from known standards (Peedee belemnite limestone for δ^{13}C and nitrogen in air for δ^{15}N):

$$\delta X = [(R_{\mathrm{sample}}/R_{\mathrm{standard}}) - 1] \times 1000 \quad (2)$$

where X is ^{13}C or ^{15}N and R is the corresponding ^{13}C/^{12}C or ^{15}N/^{14}N ratio, respectively (Peterson and Fry, 1987).

The trophic level (TL) of sailfish and their prey sampled was estimated using the equation:

$$\text{Trophic level} = (\delta^{15}\mathrm{N}_{\mathrm{consumer}} - \delta^{15}\mathrm{N}_{\mathrm{baseline}})/\mathrm{TEF} + 2 \quad (3)$$

δ^{15}N values provide an indication of the trophic level of consumers (Post, 2002). Primary producers are trophic level 1, primary consumers are trophic level 2, and so on. The trophic enrichment factor (TEF) represents the best estimate of isotopic enrichment between sailfish and its diet. We adopt a TEF of 2.4‰, the mean TEF for marine fishes based on Vanderklift and Ponsard's (2003) review of literature that reported consumer-diet δ^{15}N enrichment (Caut et al.,