Ocean Sunfish in Canadian Pacific Waters:

Summer Hotspot for a Jelly-eating Giant?

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***Abstract*— With reports of increasing gelatinous zooplankton biomass in the east Bering Sea, the presence of one of the ocean's largest jelly-eating predators, ocean sunfish *Mola mola*, in northeastern Pacific waters merits closer scrutiny. Using shipboard surveys and standard line-transect survey field protocols, the presence and absence of *M. mola* in the waters off British Columbia (Canada) were investigated over three consecutive summers between 2004 and 2006, and spring of 2007. A high-density region was located at the western edge of Queen Charlotte Sound during the summer months only. Key factors associated with this hotspot include elevated water temperature and complex bathymetry. This work establishes baseline data on an elusive yet consistent summer visitor to Canadian Pacific waters and a methodology for conducting additional *M. mola* distribution studies using surface surveys in other ocean regions.**

Keywords—abundance, density, distance sampling, distribution, line-transect, ocean sunfish, spatial model, Mola mola

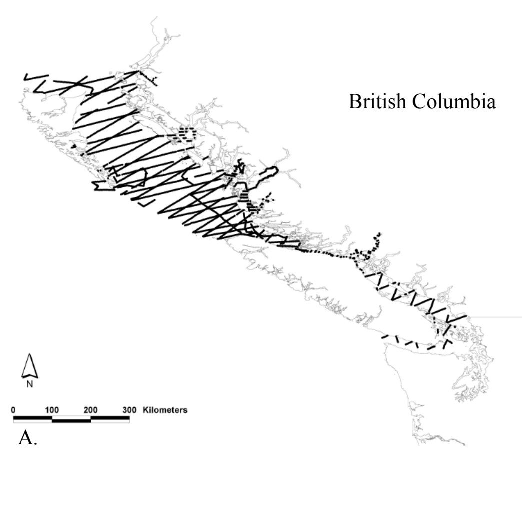
I. Introduction

Ocean sunfish, *Mola mola*, is the world's heaviest bony fish with the largest individual weighing 2.3 metric tons [1]. These distinctly-shaped, tail-less tetraodontiform fishes are opportunistic foragers in all tropical and temperate ocean basins. The species has been reported as far north as the Gulf of Alaska in the Pacific [2,3] and Narvik, Norway in the north Atlantic [4]. Its diet can contain an array of fish, invertebrates and algae [5,6,7] however, primary prey of *M. mola* is presumed to be gelatinous zooplankton based on gut analyses [8,9]. Recent stable isotope work from the Mediterranean suggests that small *M. mola*, under 1 m, consume a mix of jellies and benthic neritic prey [10] while the diet of larger individuals is comprised of a greater proportion of jellies. Amid recent reports of rising jelly blooms, specifically Chrysaora melanaster, in the east Bering Sea [11,12,13,14] the presence of one of the ocean's largest jelly-eaters in adjacent north Pacific waters merits closer investigation. The first recorded capture of *M. mola* in British Columbia dates back to July 14th, 1915 off Ucluelet on B.C.'s Vancouver Island [15]. Small to medium-sized individuals, typically under 1 m, are reported as far north as the Gulf of Alaska, however to the best of our knowledge, no formal studies have investigated presence, abundance or distribution of *M. mola* within western Canadian waters. The species is currently viewed as a vagrant appearing during El Niños and other anamalous events, rather than being a regular seasonal visitor [16]. The following work offers preliminary baseline data and methodology to reduce gaps in our knowledge of this important jelly-eating species in a rapidly changing region of the world ocean.

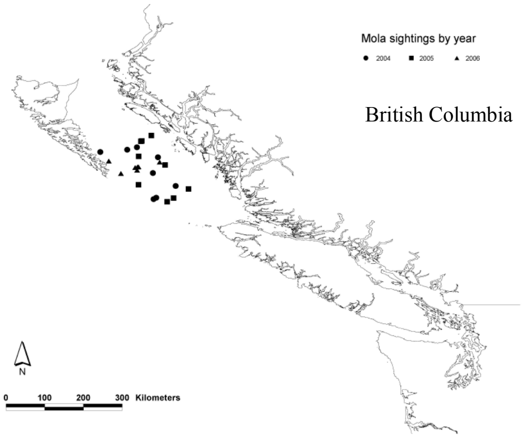
II. Methods

A. Study design and field methods

Shipboard surveys for marine mammals for British Columbia coastal waters were conducted during summers of 2004-2006 and spring 2007. Field protocols required observers to record all sightings of sunfish and visually estimate size ranges. The survey followed a systematic design, which has been described previously [17], and observers followed standard line-transect survey field protocols [18]. The survey was completed as planned in summers 2004 and 2005, but only partially completed in 2006 due to funding constraints. The survey was also completed in spring (April and May) 2007, but no sunfish were seen; data from 2007 were ignored in subsequent analyses, and resulting abundance estimates apply to average summertime abundance in Canada's Pacific continental shelf waters. The field effort resulted in a design-unbiased sample for 2004 and 2005, but an unrepresentative sampling design for 2006. Consequently, a model-based abundance estimator using generalised additive models (GAMs) [19] was used to estimate mean abundance during summers 2004-06, inclusive. Search effort (trackline covered) and sighting locations used in the analyses (i.e., those from summers 2004-06) are shown in Fig. 1 A,B shown below.



A.



B.

Fig 1: Queen Charlotte Basin Survey. (A) Search effort (black lines); (B) Ocean sunfish sightings (circles, squares and triangles by year) during 2004-6 surveys. The Queen Charlotte Basin stratum of the survey was also repeated in spring 2007, but no ocean sunfish were seen.

The observation team consisted of two observers standing on a ship with binoculars scanning at 90˚ on either side of the ship's bow and a data recorder. When a sighting was made, the observer and data recorder noted radial distance, radial angle (measured using angle boards), time, location, species or detailed comments about distinguishing features, and group size. Radial distance estimates were corrected using correction factors calculated from observer-specific distance estimation experiments, in which the relationship between observers' judged distances were regressed on true distances [20].

B. Analysis of line transect survey data

Distance sampling methods estimate density of animals through estimation of the strip width covered along a transect line [21]. Perpendicular distance data were right-truncated by 5-10%, and two standard detection function models [22] were fitted to the data using the software Distance 6.0 [23]. Animal density (the number of animals per unit area) was estimated by

$$\hat{D} = \frac{n \cdot \hat{f}(0) \cdot \hat{\mathrm{E}}(s)}{2L} \quad (1)$$

where: n is the number of schools observed within truncation distance of the trackline; $\hat{f}(0)$ is the estimated probability density function of perpendicular distances, evaluated at zero distance (and is the reciprocal of the effective strip half-width); $\hat{\mathrm{E}}(s)$ is the estimated mean school size; and L is the total length of trackline.

The two candidate models for the detection function were the half-normal and hazard-rate models [24]. A spatially explicit model was used to account for the non-systematic placement of tracklines surveyed in 2006 using methods described previously [25,26]. A descriptive GAM was constructed from effort and sightings data; the model was used to predict sunfish density at each spatial location in the survey region, and numerical integration of the density estimates provided an estimate of total sunfish abundance. Effort and sightings data were modelled using the "count" method for interpolating density between tracklines [27], in which probability of encountering a sunfish along a 1nm segment of trackline was modelled as a two-dimensional tensor product smooth function of latitude and longitude [28], a one-dimensional smooth spline of water depth, and an offset term for the area effectively searched in each segment. GAMs were fitted using the Density Surface Modelling engine packaged in program Distance 6.0 [29]. The model framework was of the form

$$\mathrm{E}(n_i) = \exp\left[\ln(2 l_i w_i \hat{p}_i) + \beta_0 + \sum_k f_k(z_{ik})\right] \quad (2)$$

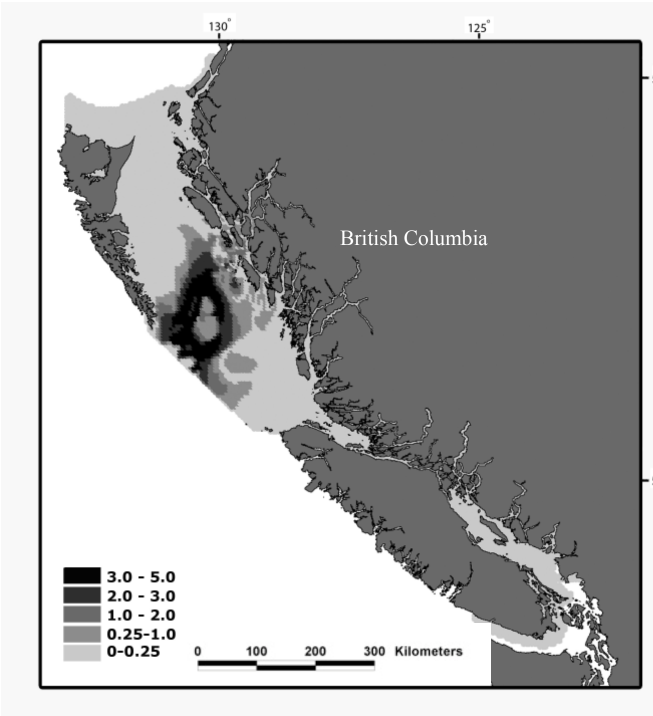
where: n_i is the number of detected schools in the i^{th} segment; l_i is the length of the i^{th} segment; w_i is the truncation distance of the i^{th} segment; $\hat{p}_i$ is the estimated probability of detection of a school in the i^{th} segment; β_0 is a parameter to be estimated; and z_{ik} represents the value of the k^{th} explanatory spatial variable in the i^{th} segment, which is a smooth function, f_k, of the explanatory variable.

After fitting a descriptive model, a gridded (4 nm^2 or 13.7 km^2) dataset was passed to the descriptive model. The output of the model was a predicted density of sunfish in each grid cell. A nonparametric bootstrap was performed to combine the detection function fitting, size bias regression, spatial modelling, model prediction and abundance estimation steps outlined above. For the bootstrap analysis, 499 bootstrap resample datasets were generated by sampling transect lines with replacement.

III. RESULTS

A total of 3,377 nm (6,254 km) of trackline was surveyed. Field effort included data collected from: 6-21 June, and 4 July -15 August, 2004; 1-29 August 2005; and 2-19 August and 24-29 September 2006. A total of 25 sunfish sightings were recorded during the surveys (23 solitary animals, and 2 pairs). Nearly all individuals were estimated to be between 1 to 2 m total length, which is beyond the size at which schooling typically takes place. One individual however was noticeably smaller, and the observer judged its size to be approximately 45 cm. The number of sightings was below the 60-80 sightings typically recommended for fitting a detection function [30], but a half-normal detection function with a 140 m truncation provided a good fit to the data. This is consistent with standard distance sampling methods, in which the farthest 5-10% of sightings are truncated to improve fit of the detection function [31].

The observed concentration of sunfish was located at the shelf break over the heads of submarine canyons, such as Moresby Trough, over adjacent banks of western Queen



Charlotte Sound, and extended shoreward about half-way across the continental shelf towards mainland BC (Fig. 1, Fig. 2). The seaward extent of this aggregation is unknown, as the survey area did not continue seaward off the continental shelf break.

Fig. 2 Predicted sunfish density (interpolated density in predicted number of individuals in each grid square), as predicted from the GAM in British Columbian waters. Note the highest-density region (the 'hotspot') is located at the western edge of the Queen Charlotte Sound.

Abundance of sunfish in the study area was estimated from the model to be 2,767 sunfish (CV=0.15; 95% confidence intervals: 2,065-3,708) in a study area of approximately 88,420 km^2 [32]. The number of animals at depth is not known, as this concentration of sunfish was indicated only by surface observations from a visual line transect survey, and consequently represents a minimum estimate of abundance of all surface-oriented sunfish in the area at the time of the survey. Sightings however tended to occur in waters with a median depth of 220 m, range 48-435 m. *M. mola* were not spotted in the deepest waters surveyed (1043 m), but were seen in waters deeper than the median (120 m). The total population is likely higher than this estimate given that *M. mola* are only visible during excellent conditions with a calm sea state and are known to engage in frequent dives to depths below 100 m [33,34].

IV. Discussion

This work offers a useful methodology for conducting pilot surveys of *M. mola* distribution across large areas that could be opportunistically combined with ongoing cetacean and turtle surveys worldwide and other surface sampling protocols. This study suggests *M. mola* may be more common than previously thought in western Canadian waters during summer months and may qualify as a regular seasonal inhabitant. The extent to which this species occupies northern waters outside of summer has not been rigorously investigated, however no *M. mola* were spotted when the systematic survey was repeated in the spring months of April and May in 2007. It is likely that *M. mola* seasonally migrate into higher latitudes taking advantage of elevated productivity levels during the long days of summer similar to other species such as leatherback turtles, *Dermochelys coriacea* [35,36] and basking sharks *Cetorhinus maximus* [37]. Such summer migratory movements have been reported for *M. mola* off Japan [38] and in the north Atlantic [39].

Temperature also most likely plays a role in preferred aggregation areas. Studies of *M. mola* in the western Pacific report the species has an impressive thermal tolerance (2-20˚C during a single dive) and an overall temperature preference between 13-21˚C (> 86% of time) [40]. During 2005, when our CTD data were best sampled, sea surface temperatures (SST) in the survey region ranged from 10-18 ˚C. The regions of highest sunfish density off Queen Charlotte sound were at the high end of this range (16-18 ˚C). According to the Canadian Department of Fisheries and Oceans, the Pacific coast of Canada was warmer and drier than normal in 2005 with warm conditions in all BC marine ecosystems [41]. Warm sea temperatures reduced vertical mixing in near-surface and deep-sea regions and reduced the supply of plant nutrients into the surface layers of the northeast Pacific Ocean and the spring outburst of plankton was delayed in 2005. A more complete understanding of factors driving sunfish distribution in this region will require more field work and more sophisticated analyses on a wider range of oceanographic variables. But our preliminary examination suggests that the sunfish hotspot closely matches a warm-water ring observed in summer 2005. We consider the link to sea surface temperature to be a strong hypothesis to test in future. More detailed analyses of shifting oceanic factors including primary productivity, eddie kinetic energy, dissolved oxygen levels through the water column and frontal probability index, coupled with additional year-round surveys and satellite tagging will offer valuable insight into the prevalence and importance of this species in northern waters and the conditions surrounding potential ocean sunfish hotspots.

A growing number of studies are reporting unusual marine species in northern latitudes with presumed links to anthropogenic climate change [42]. Jelly populations, for example, are opportunistic and can respond quickly to physical and biological changes in the ocean by increasing production rates of young jellies from the benthic polyp stage, and by increasing feeding, growth, and reproduction of the medusa stage under favorable conditions. It is important to note however that seemingly sudden appearances of otherwise elusive or uncommon species, such as salmon and blue sharks [43] may also be linked to increased sampling efforts and public presence in the water, although that would not explain the absence of sightings in our spring 2007 survey. Establishing solid baseline data on *M. mola* populations in tropical and temperate latitudes will help discern whether this species is indeed increasing in numbers in the higher latitudes, responding to increases in potential prey sources like jellies or simply remaining a steadfast, albeit elusive, summer resident in western Canadian waters and beyond. For now, it would appear that *M. mola* is a more common summertime visitor to Canada's Pacific waters than previously presumed, and we suggest that its conservation status should be assessed periodically under relevant legislation like any other Canadian wildlife species.

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