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Seafloor mapping and landscape ecology analyses used to monitor variations in spawning site preference and benthic egg mop abundance for the California market squid (*Doryteuthis opalescens*)

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ABSTRACT

The California squid fishery is concentrated largely on nearshore squid spawning aggregations. Because of this practice a central concern for sustainable squid fisheries in California is to determine whether reproductive activities and subsequent egg laying occur at rates that are sufficient to support harvestable populations of this sub-annual species. Using high-resolution data collected via acoustic mapping methodology, we estimated a 99% decrease in egg mops abundance from 2005 to 2007. Sidescan sonar images from detailed benthic mapping suggest that although squids prefer a sandy substrate as their primary egg mop habitat, the depths across which egg mops were distributed differed significantly between surveys and spatial distribution of egg mops varied across years on this large spawning ground. Our results suggest that sidescan sonar surveys could serve as an important tool used to aid sustainable management of the California market squid fishery through the monitoring, designation and adaptive management of seasonally variable no-take spawning zones and can help in developing stock assessments of this commercially important species.

1. Introduction

The life history characteristics of some marine species make them more susceptible to overexploitation than others. For example, species that form spawning aggregations, such as many species of squid and grouper, are extremely vulnerable to overexploitation due to fishing practices that target their annual spawning grounds (Coleman et al., 1996). In order to develop successful management strategies for species that aggregate during spawning, there is a need for more and better data on variation in the species' spatial and temporal use of spawning habitats. The California market squid, (*Doryteuthis* (formerly *Loligo*) *opalescens*), a group spawner, potentially offers an ideal sustainable fishery due to their semelparous (spawn once and die) life history. As long as *D. opalescens* are allowed to spawn prior to being caught, the sub-annual recruitment can sustain the population (Hanlon et al., 2004; Hibberd and Pecl, 2007).

Like many loliginid squid fisheries worldwide, *D. opalescens* are captured directly on spawning sites (Butler et al., 1999) where they are lured closer to the surface using high wattage light boats and caught with large purse seines (Maxwell et al., 2004; Zeidberg et al., 2006) that can contact the seafloor when deployed over shallow spawning grounds (R. Kvitek pers com). The consequences of fishing on spawning grounds are not completely known but of serious concern (Hanlon, 1998; Sauer, 1995) because they can potentially include disruption of *D. opalescens'* complex mating and egg laying behaviors (Hanlon et al., 2004; Hanlon and Messenger, 1996) as well as dislodging egg mops from their attachment to the sandy substrate.

Doryteuthis opalescens is a comparatively small squid that inhabits the middle trophic level in the California and Alaska current systems along the coast of North America (Morejohn et al., 1978; Zeidberg et al., 2006). They are found from the southern tip of Baja California to southeastern Alaska (Hixon, 1983). Market squid is an important species for both the commercial fishery and a vital forage species for a large number of birds, mammals, and fishes (Zeidberg et al., 2006). They spend the majority of their 6–9 month lifespan offshore, returning inshore solely to spawn (Hixon, 1983; Yang et al., 1986). During spawning, females lay a cluster of egg capsules in nearshore, shallow waters on sandy substrates (Hixon, 1983).

As a possible solution to potentially harmful effects of fishing directly on spawning sites, the California Department of Fish and Game (CDFG) recommended the adoption of no-take spawning areas (Mangel et al., 2002). The Marine Life Protection Act (MLPA) in California has helped to protect some important spawning areas through the designation of marine protected areas; however, sites where *D. opalescens* consistently spawn (records date back more than 100 years; Fields, 1965), are not protected from fishing pressure. As a

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monitored species there are no mandatory harvest limits but there are seasonal catch limitations, monitoring programs, and a permit system (NMFS, 2009). Overall, the lack of data on squid population size, fishing effort, and the spawner-recruit relationship has made management unorthodox and difficult (Maxwell et al., 2005). The methods used in this study could provide a means for managers to estimate biomass of both reproductive output and the population and, as a result, come up with stock assessments for this commercially important species.

Previous studies have demonstrated that sidescan sonar can be used to accurately map the locations of spawning grounds for *D. opalescens* (Foote et al., 2006). The purpose of this study is to build upon those results from previous studies and begin to look at how the use of sidescan sonar to map the location of egg mops can answer questions about the ecology of *D. opalescens* by testing the following hypotheses:

Hypothesis 1. *D. opalescens* show a consistent interannual preference for specific habitat types and depths.

Hypothesis 2. *D. opalescens* consistently spawn in the same location each year, and do not use immediately adjacent areas of similar depth and substrate type.

Hypothesis 3. Backscatter data collected by a hull mounted multibeam system can be used as an accurate and efficient way to map *D. opalescens* spawning grounds.

Understanding spatial and temporal habitat use by spawning *D. opalescens* is critical in determining whether static or dynamic no-take spawning zones would be the most effective strategy for sustainable management of this valuable fishery.

2. Materials and methods

2.1. Data acquisition and processing

Five consecutive sidescan sonar and video surveys of squid egg beds were conducted over three years on the traditional fishing grounds of Monterey, CA in the southern portion of Monterey Bay. The survey dates were: summer 2005 (31 May 2005–1 June 2005); spring, summer, and fall 2006 (28 April 2006–2 May 2006, 9 June 2006–15 June 2006, 1 September 2006–2 September 2006); and summer 2007 (27 May 2007–2 June 2007). The summer surveys from each year were used for detection of inter-annual variation in egg mop distribution and the three surveys completed in 2006 were used to estimate intra-annual variation. All data were collected within a 1.46 km^2 study area along the southeast shore of Monterey Peninsula (36°37′02″ N, 121°53′27″ W). The squid egg beds are predominantly found in the sandy substrates beyond the nearshore kelp beds. Once mapped, we verified the locations of the squid egg beds using a Deep Blue Pro color camera with a 3.6 mm wide-angle lens, focus fixed at 2.54 cm and a National Television System Committee (NTSC) composite video image resolution of 480 TV lines. Survey methods for mapping the egg beds are described in detail in Foote et al. (2006).

In addition to sidescan sonar, multibeam sonar data were collected within the study area using a pole-mounted Reson SeaBat 8101 multibeam sonar system. Unlike sidescan sonar, which collects information on the intensity of return of the acoustic signal and can distinguish between different substrate types on the seafloor (i.e. rock will return a stronger acoustic signal than sand), multibeam sonar simply records the two-way travel time of the sound to calculate the depth of the seafloor at 1.5° intervals across a 150° swath yielding high-density depth sounding data across the entire survey area. Following acquisition, the multibeam data were imported into CARIS HIPS software where they were processed using standard hydrographic data cleaning procedures (see CARIS, 2006 for a description) and the data were exported from CARIS as regularly spaced (2 m) XYZ points. These XYZs were converted into a digital elevation model (DEM) in ESRI Grid format for GIS analysis.

Because *D. opalescens* show a preference for particular habitat characteristics when depositing their eggs on the seafloor (Hanlon, 1998; Hanlon et al., 2004; Hurley, 1977; Zeidberg and Hamner, 2002), the following habitat rasters were algorithmically derived from the DEM (ArcGIS 9.2 ESRI®) for determining the relationship between spawning location and habitat: slope, vector ruggedness measure (VRM), and topographic position index (TPI). A slope raster was derived from the bathymetric DEM using the ArcGIS Spatial Analyst extension. A VRM grid, which measures the complexity of the seafloor, was created using the Terrain Tools extension for ArcGIS 9.2. The final habitat metric derived was topographic position index (TPI), which indicates the position of a given point in the overall surrounding landscape (i.e. peaks, slopes, valleys, crevices, etc.). The TPI analysis employed in this study was done using the algorithm of Weiss (2001), which uses an annulus (“donut”) shaped neighborhood.

2.2. Using sidescan to quantify squid eggs

The digital images from each sidescan survey were brought into (ArcGIS 9.2 ESRI®) to quantify the visible egg beds. Prior to the GIS analysis, a single technician was trained to distinguish between egg beds and other anomalies in the image such as rocks, sediment changes, and artifacts by comparison of georeferenced video and sidescan sonar imagery. Once trained, the technician traced polygons around each individual egg mop for all of the surveys without further aid of the video data. Area was calculated for each egg mop to give the total coverage of egg mops within each sidescan survey. Over 18,000 egg mops were identified during the three year study.

2.3. Squid egg depth distribution

To determine if *D. opalescens* has a depth preference within which it deposits eggs, the egg mop polygons from each survey were used to test for differences in the depth distribution between and within years. The Zonal Statistics tool within the Spatial Analyst Tools in ArcGIS 9.2 was used to find the average depth for each egg mop polygon from all the surveys. These depth values were then exported from ArcMap for statistical analysis.

To determine whether the data met the assumptions for an ANOVA, the distribution of the depth data were compared to the normal distribution using the Kolmogorov–Smirnov test. Because the data were significantly different from the normal distribution ($p<0.000$), a non-parametric Kruskal–Wallis test was used to determine if there was a significant relationship between distribution and egg mop depth.

2.4. Spatial distribution of egg mops

To determine if there was significant spatial clustering of egg mops within each of the years used in this study, separate Ripley's K analyses were used. Ripley's K provides not only an estimate of spatial clustering within an ecosystem but can provide insight on the scales across which clustering occurs and the potential environmental processes that drive spatial patterning in ecological systems by using the distance between all pairs of points in the study area (Kuuluvainen et al., 1996; Ripley, 1981). Ripley's K analyses were completed using the Multi-Distance Spatial Cluster Analysis (Ripley's K Function) within ArcGIS 9.2. If significant clustering was found, a Chi-square test of association was then conducted for the following habitat variables at each spatial scale to ascertain if clustering was significantly associated with different categorical levels of depth, slope, vector ruggedness measure (VRM), and topographic position index (TPI). Chi-square residuals were then analyzed to estimate the relative contribution of each within variable