Size assessment of bucket-trap holes to reduce capture of immature hagfish

Travis H. Tanaka* and Kathryn Crane

California Department of Fish and Wildlife, Marine Region, 20 Lower Ragsdale Drive, Suite 100, Monterey, CA 93940, USA (THT)

California Department of Fish and Wildlife, Marine Region, 619 Second Street, Eureka, CA 95501,USA (KC)

**Correspondent: Travis.Tanaka@wildlife.ca.gov*

In California, the commercial fishery for Pacific hagfish (*Eptatretus stoutii*) has exported over one million pounds annually in recent years, primarily to South Korea where they are considered a delicacy. Comparatively little research exists to support management decisions for this species. In an effort to support ongoing conservation efforts, the California Department of Fish and Wildlife (DFW) sought to evaluate the influence of trap hole diameter, which is presently unregulated, on the take of immature hagfish and other characteristics of the catch. Using standard 5-gallon bucket trap gear, we tested four hole diameters, some of which are currently or have been previously used by the fishery; 9.7 mm, 12.7 mm, 14.2 mm, and 16.0 mm. Although the take of immature hagfish was not completely eliminated except when the largest of these hole diameters was used, a significant reduction in the percentage of immature hagfish occurred between 12.7 and 14.2 mm. We found that market quality increased with increasing hole diameter, yet overall catch volume decreased, suggesting that hole diameter currently employed by the fishermen represents a conscious tradeoff between these competing factors. Total bycatch over the course of the 4-day study was minimal, composed of one octopus (*Octopus spp*.) and one Pacific sanddab (*Citharichys sordidus*).

Key words: California, bucket traps, *Eptatretus stoutii*, gonad condition, hole diameter, immature, Pacific hagfish,

The Pacific hagfish (*Eptatretus stoutii*) is one of approximately 60 species within the hagfish family (Myxinidae), which constitutes the most primitive family of fishes. Hagfish inhabit relatively deep, temperate regions of the world's oceans, and are highly adapted to the low oxygen (Cox *et al* 2011) and high salinity conditions (Adam and Strahan 1963) that occur at depth. They may be the most abundant fish inhabiting the upper continental slope, though previous population estimates are limited and likely underestimate abundance due to their cryptic burrowing behavior (Martini 1998). Hagfish are ecologically important, providing an ecosystem service as a scavenger and as a food source to many species (Martini 1998). Pacific hagfish in particular were shown to provide a significant portion of the year-round diet for the harbor seal (*Phoca vitulina*) (Hanson 1993, Oxman 1995).

In California, an unprecedented commercial fishery for hagfish emerged in the late 1980's to provide skins for the South Korean "eel skin" industry and peaked in 1990 with approximately 4.9 million pounds in landings. The fishery is managed by the California Department of Fish and Wildlife (CDFW). Soon thereafter landings abruptly declined for unknown reasons and remained low until 2005, when the fishery re-emerged, this time for human consumption instead of for skins. Since 2007, commercial landings for hagfish have remained relatively stable and have ranged from one to two million pounds annually. In 2013, 1.3 million pounds of hagfish were landed in California, generating approximately $1 million in ex-vessel revenue in (CDFW landings data). Hagfish are caught along the entire length of the state, although Oceanside, Morro Bay, and the Eureka area are the primary ports of landing.

Though Pacific hagfish have been studied extensively in an evolutionary context, there is relatively limited information on the species as it relates to fishery management. There is some evidence that they are relatively slow-growing and long-lived and they may reach ages upward of 25 years (Nakamura 1994, Johnson 1994). Several studies suggest that they have a relatively low fecundity, with females only carrying 20-30 eggs per breeding cycle (Gorbman and Dickhoff 1978, Kato 1990). Female hagfish are estimated to attain reproductive maturity somewhere between 7 and 12 years of age (Nakamura 1994), while males mature at a somewhat younger age (Reid 1990). These life history characteristics suggest that hagfish may be susceptible to excessive fishing pressure, provided effective management actions are not implemented.

Limiting the take of immature fish is a common fishery management strategy and one that has not yet been applied to the Pacific hagfish fishery. At present, the fishery is subject to relatively few regulations, it is open access, and it has no quota or other direct limitations imposed on catch volume. There is, however, a gear limitation in that fishermen may not exceed 500 Korean-style traps or 200 20-L bucket traps (Figure 1). The bucket trap is the preferred method of take for California fishermen due to its larger capacity. Hagfish traps have many holes drilled (bucket) or built in (Korean) which allow water to flow through the trap; this helps the bucket ascend/descend during deployment and retrieval. The holes also provide an additional means for hagfish to enter the trap and an opportunity for small hagfish to exit the hole. CDFW currently does not have a minimum hole diameter requirement for hagfish traps, and at present the fishery uses hole diameters ranging from 9.7-16 mm.

Previous trap studies in California have examined various aspects of hagfish catch characteristics, but none so far have examined the influence of hole diameter on the take of immature hagfish. Melvin and Osborn (1992) tested variations of trap gear, including hole diameter, on mean hagfish size and catch volume. However, the main purpose of their study was to provide industry with information on identifying ways to control trap-induced skin quality issues, and gear development for selecting a higher proportion of larger hagfish. Johnson (1994) used Korean style traps in an effort to test hagfish distribution at various depths and retain samples for a maturity study, but did not examine the effects of variations in trap gear. In our study, conducted in March 2013, we sought to provide specific information which can be directly incorporated into fishery management decisions by testing the influence of trap hole diameter on the retention of immature hagfish. We also assessed the potential economic consequences of regulating hole diameter by evaluating its relationship to overall catch volume and market quality.

MATERIALS AND METHODS

The experimental design used in this study was adapted from previous research efforts (Melvin and Osborn 1992), but focused on examining size distribution of catch and retention of immature fish. We also incorporated hagfish fishermen knowledge into the study design to improve catch rate and provide results which were more reflective of the hagfish fishery itself. We interviewed current fishery participants from Eureka, Morro Bay, and Oceanside either in person or by phone to determine the number of traps typically fished, the hole diameter(s) used in the fishery, and the reason(s) that each hole diameter was selected. In addition, each fisherman provided us with information on their preferred bait type, as well as the typical duration of time that they soak their traps. Based on fishermen responses, we were able to: 1.) test the influence of hole diameters actually used by the industry, 2.) increase our sampling success, and 3.) develop successful working relationships with fishery participants.

Sampling procedures — A typical bucket trap consists of a 20-L bucket, a single cone-shaped entrance funnel fixed to the bucket lid, a weight fixed to the inside wall of the bucket to orient it upon landing, and many drilled holes in the walls and bottom of the bucket. A total of ninety-six 20-L bucket traps were constructed, which were secured to four 250-m strings (ground lines), with twenty-four traps per string (Figure 2). Each string contained six replicate traps each of the following hole diameters: 9.7 mm, 12.7 mm, 14.2 mm, 16.0 mm. Traps were placed 10.7 m apart along the string in alternating order. Each trap was secured to the string with a short leash. All traps were standardized, each with 50 holes drilled in the same pattern, one entry funnel, and a single weight to ensure correct orientation when the trap contacted the sea floor. All sampling was conducted onboard the F/V *Donna Kathleen* and gear was deployed by the experienced crew.

The study was conducted in Monterey Bay, due west of Moss Landing (Figure 3). This study area was chosen because hagfish were fished here commercially in the recent past (CDFW commercial landings data, trap log data), and because the site is located in the geographic center of the California fishery. Areas were targeted within Monterey Bay characterized by soft benthic sediment and were identified by the captain’s interpretation of the onboard sonar signature. Based on information gleaned from commercial fishermen interviews, previous research, and log book data, we initially prospected depths between 90 and 150 m, the reported depth range where

Pacific hagfish were fished in this area. An initial, one-day prospecting survey was conducted within the targeted area to locate hagfish. On the prospecting day (day 1), a subset of the sampling gear that included only 72 traps of the three smallest hole diameters was deployed in a series of short (<4 hour) trap soaks to identify the presence or absence of hagfish. Locations where hagfish were present were recorded and used as sampling sites in the subsequent days of standardized sampling, but the fish captured were not used in any of the analyses.

On each of days 2-4, we deployed the four standardized strings of bucket traps, baited with approximately 0.7 kg of sardines per trap, at sites identified as hagfish habitat on day 1. We soaked each string overnight for up to 24 hours, and retrieved strings in the order of deployment to maintain soak times as consistent as possible. Between each deployment, trap strings were moved up to 0.5 degrees latitude to avoid fishing previously fished areas. Fishing depth range was 100 to 160 m based on the success from day 1.

Upon retrieval, we counted all hagfish captured in each trap and weighed them in aggregate to the nearest tenth of a kilogram. We recorded the hagfish count per trap, total hagfish weight per trap, trap hole diameter, and string location. We also recorded any observed bycatch by species and condition at capture (e.g. live, dead, etc.). For the sampling that occurred on days 2 and 3, we retained five randomly selected hagfish from each of the first two trap hole diameter replicates from each string, resulting in 40 hagfish retained by each hole diameter per day. On day 4, we retained five randomly selected hagfish from the first three hole diameter replicates for the first two strings, resulting in a total of 60 randomly sampled hagfish per hole diameter. All remaining hagfish were released immediately in live condition. All retained hagfish were placed in labeled plastic bags, stored on ice for the duration of the cruise, and frozen at the conclusion of each sampling day.

Laboratory and Statistical Analyses.—Upon return to the laboratory, all sub-sampled fish were defrosted and 125 of the 160 fish collected per hole diameter were randomly sampled and examined for further analysis. Weight (grams) and length (mm) were measured for each individual fish. Since hagfish are not sexually dimorphic, sex was determined for each individual by making an incision along the ventral side, exposing either the testis or ovarian tissue. Following pre-established criteria (Barss 1993), we determined gonad condition using a 1-5 scale (Immature, Maturing, Mature-developing, Mature-developed, and Mature-spent) for each individual where female gonad condition is dependent on the stage of the egg (total egg length and presence/ absence of spent egg capsules),. For both sexes, condition 1 indicated an immature fish, condition 2 indicated the beginning stages of gonad maturation, and conditions 3 and 4 were nearly or fully in spawning condition, respectively.

Hagfish of a mature size appeared to oscillate among conditions 2-5. Nakamura (1991) noted that the greatest number of 15 mm eggs (condition 3) occurred during the fall quarter., However, he observed condition 1-4 females throughout the year. We developed a rough approximation of the size at first maturity for females by determining the size above which no condition 1 fish were observed out of our sub-sampled fish. We compared this size to histograms of combined sub-sampled female length data from each hole diameter size, and the percentage of immature hagfish was determined. To assess whether sub-samples from the four treatments (i.e. hole diameters) were significantly different from one another, we performed two, one-way analysis of variance (ANOVA) tests. We used hole diameter as the explanatory factor for either length or weight observations.

To evaluate the possible economic consequences of variations in hole diameter, we examined both overall catch volume and the number of hagfish per kilogram within each bucket, or count-per-kilogram (CPkg). While catch volume (kg) is relatively straightforward, the reasoning behind examining CPkg originates from a market quality perspective. Korean dealers historically preferred hagfish 356 mm total length (TL) or greater (Kato 1990), but currently the hagfish export market emphasizes weight over length and additionally, live hagfish are virtually impossible to measure in length. CPkg is a metric utilized by the industry to evaluate size, and subsequently assign a grade to the catch. Hagfish exporters typically desire a maximum of 8 to 9 hagfish per kilogram.

RESULTS

The survey collectively yielded 7,595 hagfish weighing 825 kg (Table 1). The mean soak time was 21.6 hr, ranging from 19.63 -24.57 hr. However, six of the 288 buckets included in the study design (96 traps per day times three days) were either accidently left off of a string prior to deployment or did not fish correctly due to user error. One of the missing traps contained 9.7 mm holes, one had 12.7 mm, one had 14.2 mm, and three contained 16.0 mm holes. In order to make the total count and weight of fish captured by each hole diameter comparable, the missing trap data was replaced with the overall mean count and weight per trap for each hole diameter.

Based on two separate one-way ANOVA's conducted on the randomly sub-sampled catch data, we determined that hagfish length ($F_{3,496}$ = 9.315, $P < 0.0001$) and hagfish weight ($F_{3,496}$ = 12.52, $P < 0.0001$) were significantly different among the four hole diameters tested (Table 2). As hole diameter increased, the range in length and weight of fish decreased, demonstrating that the smaller hole diameters capture a larger spectrum of the population. Accordingly, CPkg also decreased, indicating average size and market quality increased with increasing hole diameter.

As hole diameter increased, CPkg did not reach the desired market maximum threshold of 8 until the second largest hole diameter (15.88 mm) was employed (Figure 4). Of all of the sub-sampled hagfish dissected in this study (n=500), we found no mature female hagfish (condition 2 or higher) less than 338 mm TL. The proportion of hagfish below 338 mm TL in the catch decreased as hole diameter increased, ranging from 17.5 to 0% (Figure 4).

The total bycatch for the study included one octopus (*Octopus* spp.) and one Pacific sanddab (*Citharichys sordidus*), which were both in live condition.

DISCUSSION

We found that trap hole diameter, which influences size of retained hagfish, also had a large influence on the proportion of immature hagfish retained in the catch. Observed trends in hagfish size (length and/or weight) with relation to hole diameter were similar to previous research even though the diameters tested were slightly different (Melvin and Osborn 1992, Johnson 1994, Nakamura 1994). The proportion of immature fish decreased as hole diameter increased, suggesting that larger hole diameters are more desirable for fishery conservation purposes. CPkg, a proxy for overall hagfish size or quality used by the industry, also decreased as hole diameter increased, demonstrating that larger hole diameters also produced the most highly desirable fish in terms of market quality. However, overall catch volume declined precipitously with increasing hole diameter, suggesting the existence of an industry tradeoff between quality and quantity of captured hagfish.

Our rough assessment of size at first maturity appears consistent with previous research into Pacific hagfish maturity. In southern California, Pacific hagfish size at maturity was estimated to be 325 mm (Nakamura 1994), and size at 50% maturity in Oregon was 340 mm

(Barss 1993). Compared with data from our long-term monitoring of the fishery, these results fall slightly above our estimate of 338 mm to the north and slightly below our estimate to the south. This may be either a direct result of north-south differences in growth and size at maturity, or simply slight differences in sampling methodology. In either case, we used a relatively conservative estimate of size at maturity to assess retention of immature hagfish. However, knowledge of hagfish reproduction remains limited and warrants future research. Pacific hagfish populations do not exhibit seasonal reproduction, and it is common to find female hagfish carrying eggs at various stages of development throughout the year (Johnson 1994, CDFW unpublished sampling data), making assessment of mature individuals somewhat more complex.

Based on fisherman interviews, as well as previous research (Melvin and Osborn 1992), we know that trap soak time is a potentially confounding factor when assessing the effects of hole diameter on catch characteristics. Hagfish will remain within a trap until the bait source becomes exhausted, and consequently no size selection occurs for an extended period of time after trap deployment. Previous research indicates that this time period is roughly 24 hours (Melvin and Osborn 1992), though it is most likely variable depending on bait volume and hagfish abundance. In the present study, we allowed traps to soak for an average of 21.6 hours (range 19.6 to 24.6) so that we could examine the performance of escape devices while minimizing the confounding effects of shorter soak time. However, any future regulatory change involving minimum hole diameter should acknowledge these confounding effects as they relate to size retention of hagfish. As such, it may be possible for fishermen to avoid the impacts of a reduction in hole diameter on catch volume by simply reducing soak time.

Some fishermen currently use 9.7-mm hole diameters on their traps, the smallest size tested in the present study. While this hole diameter would maximize catch volume, we have demonstrated that this size hole retains a large proportion of immature-sized female hagfish. This smallest size also produces the lowest percentage of high quality fish, as reported by the industry, which may be economically offset by the large volume. As the diameter increases, the proportion of immature hagfish retained is greatly reduced and by 16.0 mm immature hagfish are virtually absent. From a conservation and market quality perspective, the largest hole diameter would clearly benefit the fishery by protecting the immature proportion of the population and by ensuring the lowest CPkg for the industry. However, this benefit is clearly offset by the drastic reduction in catch that occurs with increasing hole diameter, suggesting the need to identify an appropriate conservation-industry compromise in the event of future regulatory action.

ACKNOWLEDGMENTS

I acknowledge the following for their contributions to this study: T. and D. Maricich (*F/V Donna Kathleen*), CFR West and P. Nelson (executive director-CFR West, science crew), and CDFW staff: K. Lesyna (science crew), K. Oda (trap construction/science crew), D. Osorio (trap construction and science crew), M. Parker (lab dissections), M. Pefok (science crew), and P. Reilly (trap construction, science crew and document review).

Literature Cited

Adam, H., and R. Strahan. 1963. Notes on the habitat, aquarium maintenance, and experimental use of hagfishes. In *The Biology of Myxine. Eds. Brodal, Alf and Ragnar Fange. Oslo: Grondahl & Son*.

Barss, W. H. 1993. Pacific hagfish, *Eptatretus stoutii*, and black hagfish, *E. deani*: the Oregon fishery and port sampling observations, 1988-92. Marine Fisheries Review 55(4):19-30.

Cox, G.K., E. Sandblom, J.G. Richards, and A.P. Farrell. 2011. Anoxic survival of the Pacific hagfish (Eptatretus stoutii). Journal of Comparative Physiology B. 181: 361-371.

Dean, B. 1898. On the development of the Californian hagfish *Bdellostoma stouti* Lockington. Quart J Micr Sci 40:269-279

Gorbman, A. and W.W. Dickhoff. 1978. Endocrine control of reproduction in hagfish. In *Comparative Endocrinology*. P. J. Gaillard and H.H. Boer, Eds. pp. 49-54. Elsevier/North Holland Biomedical Press, Amsterdam, Holland.

Hanson, L. C. 1993. The foraging ecology of the harbor seals, Phoca vitulina, and California sea lions, Zalophus californianus, at the mouth of the Russian River, California. PhD Dissertation, Sonoma State University.

Johnson, E.W. 1994. Aspects of the biology of the Pacific (*Eptatretus stoutii*) and black (*Eptatretus deani*) hagfishes: from Monterey Bay, California. M.S. Thesis. Chico State University. Fresno, CA.

Kato, S. 1990. Report on the biology of Pacific hagfish, *Eptatretus stoutii* and the development of its fishery in California. Technical Report, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Tiburon, CA.

Martini, F. H. 1998. The ecology of hagfishes. In *The biology of hagfishes*. pp. 57-77. Springer Netherlands.

Melvin, E.F. and S.A. Osborn. 1992. Development of the west coast fishery for Pacific Hagfish –Final Report to the Saltonstall-Kennedy Program, National Marine Fisheries Service. WSG-AS 92-02, Washington Sea Grant Program.

Nakamura, R. 1991. A survey of the Pacific hagfish resource off the central California coast. Final Report to the Office of Environmental Protection, Marine Fisheries Impacts Program. Contract Agreement Number: A-800-184.

Nakamura, R. 1994. Growth and age of Pacific hagfish *Eptatretus stoutii* off the central California coast. National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Final Report NA27FD0169-01.

Oxman, D. S. (1995). Seasonal abundance, movements, and food habits of harbor seals *(Phoca vitulina richardsi)* in Elkhorn Slough, California. PhD Dissertation, California State University Stanislaus and Moss Landing Marine Laboratories.

Reid, R. 1990. Research on the fishery and biology of the hagfish. California Environmental Protection Agency. Technical Report.