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SIZE DIFFERENCES IN WILD AND FARMED RED ABALONE: DEVELOPING ENFORCEMENT TOOLS TO COMBAT ILLEGAL COMMERCIALIZATION

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Enforcement tools are needed to combat the illegal commercialization of wild red abalone, *Haliotis rufescens*, taken in the recreational fishery in northern California. We examine size differences between wild and farmed red abalone shells, meats and meat slices. Wild red abalone are larger in multiple measures of size distinguishing them from legally sold farmed red abalone. We find that abalone meat weights and lengths are correlated to shell length so that the original shell length of the abalone can be estimated even when the shells are not available to enforcement officers for prosecution.

INTRODUCTION

Since the statewide closure of the commercial fishery in 1997 (SB 463), it has been illegal to buy and sell abalone taken from the wild in California (Cal. Fish & Game Code Sec. 7121). Nevertheless, thousands of red abalone, *Haliotis rufescens,* taken in the recreational fishery north of San Francisco are unlawfully sold every year (Daniels and Floren 1998). This illicit commercial trade threatens the sustainability of northern California's red abalone stocks. In response to this threat, State Senator Wes Chesbro (D) is pursuing legislation that would make the illegal commercialization of wild abalone a felony. Because farmed abalone may be legally sold, a forensic method of differentiating between wild and farmed abalone is needed.

Wild red abalone are taken in the recreational fishery north of San Francisco, which is the only abalone fishery open in the state. Abalone populations in California once supported a commercial fishery landing in excess of 2,000 mt per year, but stocks declined due to overfishing, sea otter predation and disease. In southern California, some populations are <1% of their original abundances (Rogers-Bennett et al. 2002). In contrast, the wild fishery on the north coast has been sustainable with roughly 35,000 divers and pickers who fish an estimated 265,000 abalone per year in 2002 (Kalvass and

Geibel 2006). Gear restrictions prohibiting SCUBA, season closures, yearly and daily bag limits as well as size limits are used to manage this fishery.

The minimum legal size in the recreational fishery is 178 mm (7 inches), while the largest red abalone available commercially from aquaculture farms are less than 160 mm (<6.3 inches) in shell length. This difference in size is sufficient to allow enforcement officers to easily recognize the larger, recreationally caught wild abalone when they are illegally possessed for sale. If an abalone is larger than 178 mm and the shell is attached, officers can use the shell measurement to prosecute by ruling out the possibility that it was obtained lawfully from an aquaculture facility. However, if the shell is removed it is currently impossible for officers to establish its original size and thereby its illicit origin. Absent additional evidence, the only way to demonstrate that an abalone came from the wild is by its shell size. A way to back-calculate the size of an abalone shell from the meat tissue alone is needed but, to date, has not been developed.

Here we examine differences in the size of meats and meat slices from legal size wild and farmed red abalone. To do this, we have taken multiple measures of abalone size from shells, meats and meat slices from two groups: legal size wild red abalone and the largest commercially available farmed abalone. We present methods for back-calculating shell length from whole animals, meat weights, and foot area. We determined multiple measures of size for slices of abalone meat from wild and farmed red abalone. We discuss how these morphometric tools can be used by enforcement to combat the illegal commercialization of red abalone in northern California.

METHODS

Legal size red abalone (N=50) were collected from Van Damme State Park, Mendocino County in northern California (Fig. 1) in February 2002. Red abalone ranged in size from 177 to 213 mm, averaging 197.3 mm. Farmed red abalone were obtained from the Monterey Abalone Company in February 2003. Farmed red abalone (N=50) ranged in size from 148 to 160 mm, averaging 153.7mm. These were the largest farmed red abalone available for purchase in the state.

Whole abalone were measured and weighed. The length of the shell was measured along the longest axis. Abalone were removed from the shell (shucked) and the weight of the shell and whole abalone were taken separately: animal weight. The weight of the abalone foot muscle without the viscera was recorded as meat weight. Once cleaned, the abalone meat is made up of the foot which is approximately oval in shape and the muscle attachment, which is above the foot and is also oval in shape. Slices of meat which included this muscle attachment were considered center cuts. The dimensions of the meat were measured including length and width of the muscle attachment, and the height of the muscle attachment as well as the length and width of the base of the meat, and the height of the total meat. We assumed that the shape of the bottom of an abalone foot is an ellipse, so that the area was estimated using the formula for the area of an ellipse = radius of the long dimension x radius of the short dimension x π.

The abalone meat was sliced and dimensions of the slices were taken. Slices were taken from the anterior head region to the posterior back region. All slices included a

Fig. 1. Map of California showing Van Damme State Park in northern California and San Miguel Island in southern California.

portion of the center muscle attachment portion of the abalone. Edge slices were not used in the analysis. The length and height of each center cut slice of abalone from both the wild and farmed abalone were taken.

RESULTS

Whole red abalone from the wild were larger in length and weight compared with the farmed abalone. Wild abalone averaged 197 mm in shell length and 1640 g in wet weight (Fig. 2). Farmed red abalone were smaller averaging 153.7 mm shell length and 620 g in wet weight. Whole animal wet weights minus the shell were also much greater for the wild (1129 g) compared with the farmed (268 g) red abalone, as were meat weights which were 610 g for the wild and 240 g for the farmed.

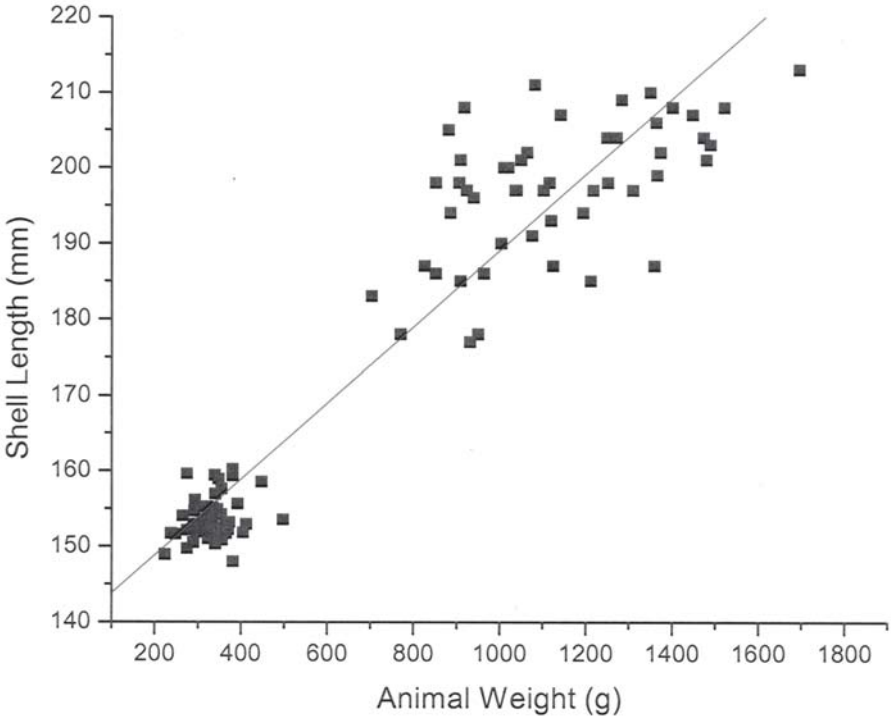

Fig. 2. Linear regression of the weight (g) of a red abalone without the shell plotted against the length of the shell (mm).

Animal weight was highly correlated ($P<0.0001$) with shell length (R=0.945, SD=7.5, N=100). This correlation makes it possible to back calculate to shell size using animal weight. Assuming that the whole intact abalone without the shell can be weighed, this can be used to estimate the length of the shell the abalone came from. Animal weights more than 781 g are estimated to be from abalone more than 178 mm in shell length using the formula:

$Y = 0.05021 X + 138.75$
where
X = Animal weight (g)
Y = Shell length (mm)

Meat weight was also highly correlated ($P<0.0001$) with shell length (R=0.872, SD=11.3, N=100). This correlation makes it possible to back-calculate shell length using the whole meat weight without the shell or the viscera (guts). Meats weights more than 453 g are estimated to be from abalone more than 178 mm in shell length (Fig. 3). This method can be used as long as there is at least ½ of the meat available for weighing. The weight of the anterior (with the head) of the abalone was not significantly different than the weight of the posterior half of the abalone (N=28) and so the meat of half the abalone could be multiplied by 2 to get the weight of the whole abalone meat. The formula converting meat weight to shell length is:

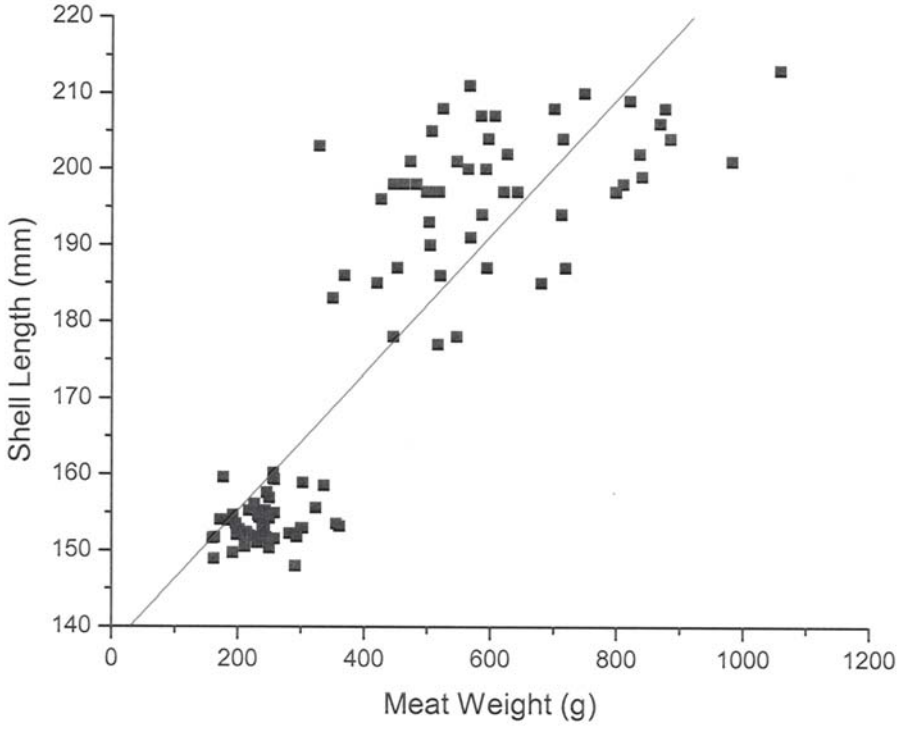

Fig. 3. Linear regression of the weight (g) of a red abalone without the shell and without the viscera plotted against the length of the shell (mm).

$Y = 0.08982\,X + 137.27$
where
X = Meat weight (g)
Y = Shell length (mm)

Foot area was also highly correlated ($P<0.0001$) with shell length (R=0.914, SD=9.32, N=100). This correlation makes it possible to back-calculate shell length using length and width measures of the foot, assuming you have more than ½ of the foot remaining. The two measures that are needed are the radius of the long dimension and the radius of the short dimension. Foot areas more than 13,184 mm^2 are estimated to be from abalone more than 178 mm in shell length (Fig. 4).

$Y = 0.00357\,X + 130.93$
where
X = Foot area (mm^2)
Y = Shell length (mm)

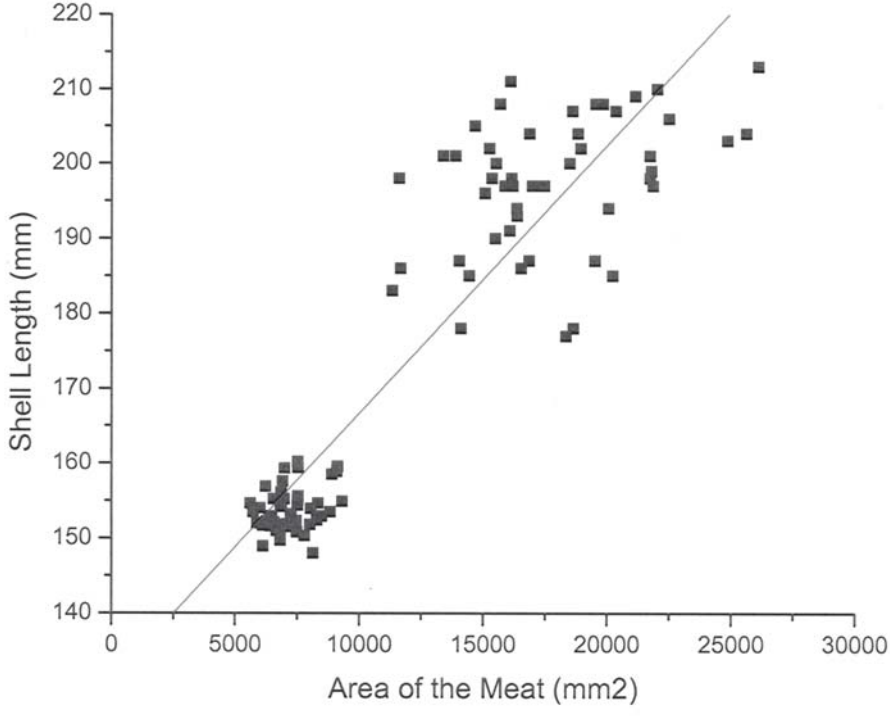

Fig. 4. Linear regression of the area of the foot of the elliptically shaped red abalone (mm^2) plotted against the length of the shell (mm).

Slices of abalone meat differed in size between the wild and farmed groups. There was no overlap between groups in the length of the abalone slices taken from the center cut of the abalone meat. Abalone meat slices <80 mm in slice length were all farmed abalone while those larger than 83 mm ranging up to 140 mm were slices from wild abalone. Slice lengths from wild abalone averaged 90.75 mm (SD=12.8) while slice lengths from farmed abalone averaged 75.00 mm (SD=7.5).

DISCUSSION

We present morphometry measures of abalone meat sizes that we demonstrate are correlated with the size of the abalone's shell. When enforcement officers find an abalone meat without the shell they will be able to use the regression relationships developed here to back-calculate an estimate of the abalone shell's length. Measures of foot weight, dimensions of foot area and the length of slices of abalone meat can all be used to estimate the original size of the abalone. Morphometric tools such as the ones developed here can be used to aid wildlife enforcement officers in prosecuting poachers illegally selling abalone in California. Furthermore, enforcement would benefit from additional legislation implementing an upper size limit for farmed abalone, explicitly prohibiting the sale of large abalone (shell length >160 mm) to distinguish them from wild abalone.

A novel form of illegal commercialization has developed in California, in which legal size (>178 mm) abalone taken in the recreational fishery are sold (A. Melvin unpublished data). Abalone are sold for personal consumption in and around the San Francisco Bay area, other metropolitan areas and in restaurants. Abalone sold in restaurants and sushi bars are usually prepared by vertically cutting 3-5mm thick slices which are served raw. Legal size abalone in the recreational fishery (>178 mm) yield slices that are larger than farmed abalone legally sold, which we show are smaller in length. This difference in size can be used to distinguish illegally sold slices of wild abalone from legally sold farmed abalone sold as sushi. Since restaurant buyers prefer larger abalone, which are widely available, it is unlikely that small wild abalone (shorts) less than 178 mm would be sold (A. Melvin personnel observation).

Fish businesses are required to maintain records of legally purchased farmed abalone for three years (F&G Code Sec 8050). Fish commercialization is pervasively regulated in California and enforcement officers may inspect all parts of the business without a warrant or probable cause (F&G Code Sec. 7702, F&G Code Sec. 1006). These laws would seem adequate to facilitate the prosecution of restaurateurs illegally selling wild caught abalone, and yet they are not. Often, prosecutors can only establish that restaurateurs did not have proper documentation. With no empirical method of distinguishing wild and farmed abalone, they cannot prosecute for illegally selling wild abalone. Failure to keep fish business records is punishable by a maximum fine of $1000 with no minimum fine. However, the unlawful sale of abalone carries a maximum fine of $40,000 (minimum $15,000) (F&G Code Sec. 12002.3(b)). Clearly, when restaurateurs are fined or reprimanded for not having farmed abalone receipts they are not receiving a punishment commensurate with the unlawful purchase/sale of abalone. Therefore, the

formulas developed here can be used by enforcement officers at the point of sale to detect the unlawful sale of abalone rather than the lesser crime of failure to maintain purchase records.

Currently (2006), there is a proposal before the California Fish and Game Commission to re-open a commercial red abalone fishery in southern California by 2008 (Fig. 1) around San Miguel Island (P. Coulston personnel communications). At this point, it is unknown what regulations might be implemented for this potential fishery, but any decision regarding size limits will directly effect the enforcement of laws prohibiting the sale of recreationally caught abalone in California and the application of the methods developed here to combat illegal commercialization.

Abalone poaching in California and elsewhere around the world is extremely lucrative and is infamous for negatively impacting the sustainability of abalone fisheries worldwide (Hauck and Sweijd 1999, Jamieson 2001, Huchette and Clavier 2004). In South Africa, abalone poachers have armed confrontations with enforcement officers and estimates of the illegal take suggest that it may be as great, or greater than the legal take, threatening to cause the collapse of the fishery (Tarr 2000). In northern California, effective enforcement will be critical to maintaining healthy abalone stocks in one of the last open abalone fisheries on the west coast of North America.

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