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**TECHNICAL NOTE**

*Leslie G. Burdett,*[1] *M.S.; Jeffrey D. Adams,*[1] *M.S.; and Wayne E. McFee,*[1] *M.S.*

# The Use of Geographic Information Systems as a Forensic Tool to Investigate Sources of Marine Mammal Entanglement in Fisheries*

**ABSTRACT:** Commercial fisheries represent a significant anthropogenic threat to marine mammal survival. Causes of marine mammal mortality are commonly determined by detailed necropsies of stranded carcasses. Gross evidence of entanglement in a fishery might include gear attached to the body, internal indications of asphyxiation and trauma, or gear markings on the epidermis. As gear is often fishery-specific, wound patterns on the epidermis that are created by entanglements in fishing gear may serve to identify possible sources of mortality. For this study, tools within the Environmental Systems Research Institute, Inc. (ESRI) ArcMap GIS software were used to create maps that outline impressions that fishing gear can leave on the epidermis of entangled marine mammals. These maps can subsequently be used to identify possible sources of fishery entanglement for the many marine mammals that wash ashore without gear attached to their carcass. Entanglement wound patterns can be visually compared with fishing gear characteristics; however, differences in scale and image quality can introduce subjectivity that might hinder source identification. The technique described herein provides an objective way to outline the unique characteristics of fishing gear and their associated wounds on entangled marine mammals. Additionally, spatial relationships are preserved as the maps are adjusted to varying scales. Whereas the initial protocol required time-consuming digitization of the outline and visual determination of the pattern interface, this new, semiautomated technique saves analyst effort and minimizes error.

**KEYWORDS:** forensic science, marine mammals, GIS, pattern matching, mortality, commercial fisheries.

Marine mammals and fisheries directly interact with each other as they often occupy similar geographic locations and compete for the same target species (1–4). As a result, marine mammals may become entangled in fishing gear, ingest fishing gear, or trail fishing apparatus as they move through their habitats (5–7). This interaction with fisheries may compromise the animal's movement, obstruct feeding ability, and ultimately lead to death (6,8).

[1]Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), National Ocean Service (NOS), National Oceanic and Atmospheric Association (NOAA), 219 Fort Johnson Rd, Charleston, SC 29412.

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| Sources of Mortality in Commercial Fisheries Predicted with GIS | *ESRI ArcNews* Fall 2003 |
| Northwest Association of Forensic Scientists Fall Meeting<br>Oral Presentation: Using Geographic Information Systems (GIS) as a Forensic Tool to Predict Sources of Human-Induced Marine Mammal Mortality Events | October 2004 |
| Southeast and Mid-Atlantic Marine Mammal Symposium<br>Poster Presentation: Working Backwards: Using Rope Impressions of Marine Mammals to Create GIS Maps That May Identify Potential Sources of Entanglement | March 2004 |
| 15th Biennial Conference on the Biology of Marine Mammals<br>Poster Presentation: Using Geographic Information Systems (GIS)<br>as a Forensic Tool to Predict Sources of Marine Mammal<br>Entanglement in Commercial Fisheries | December 2003 |

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When marine mammals strand, trained personnel conduct necropsies and sample tissues for analyses of life history parameters, pathology, and causes of mortality. Gross external examinations are made upon retrieval of a carcass, followed by internal observations of organ systems (9–11). These observations may reveal evidence of anthropogenic mortality causes such as boat collision and fishery entanglement (4,6,8–13). Evidence of interaction with a fishery may include rope marks on the epidermis, hemorrhaging, and congestion in the respiratory system and other tissues, foam found in the bronchi, and stomachs full of prey (6,9,11–13). For those animals that strand with gear attached, the source of mortality may be easily identified. In many cases, however, marine mammals strand without gear, so analyses of entanglement wounds and scars may be the only indication of fishery-related mortality (9,11–14).

Marine mammals that have been entangled in fishing gear may exhibit indentations, impressions, or abrasions on their epidermis. Because gear is often specific to a particular fishery, unique characteristics of these epidermal markings may indicate the fishery responsible for the entanglement. For instance, marine mammals that are entangled in net fisheries often have hatch marks along the body, whereas marine mammals that have been entangled in rope may have patterned impressions that vary with braiding type (9,12). Woodward et al. demonstrated that the impression made by fishing gear reflected the braiding type, but appearance of the impression was affected by the deterioration of the gear (14). These unique epidermal impressions can be related to a specific fishery or gear manufacturer. This type of pattern comparison is a common forensic technique that has been used for the identification of unique vehicle parts in theft cases (15), ballistic image matching (16,17), and human and dental identification (18,19). In most of these cases, complex algorithms and specialized computer databases have been developed for analyses (16,17,19). This paper describes a technique

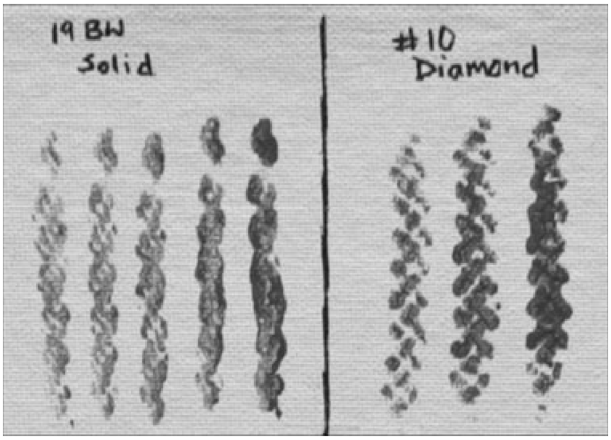


FIG. 1—*Imprints of two rope types created by covering rope with paint and pressing onto a canvas board.*

used to compare marine mammal entanglement wounds of unknown origin with commercial fishery gear types using tools and extensions within Geographic Information Systems (GIS) software. Historically, GIS has been used by marine mammal scientists to illustrate marine mammal habitat use, distribution, residency patterns, and movement (20–26). In this study, we used image processing tools within Environmental Systems Research Institute, Inc. (ESRI, Redlands, CA) ArcMap GIS software (ESRI) to develop maps of different fishing gear types and entanglement wounds on stranded carcasses that wash ashore without gear.

## Methods

Outlines of impressions that fishing gear would leave on the epidermis of an entangled animal were first simulated using paint and canvas. Sections of rope with different braiding styles and diameters were covered with paint and pressed onto a canvas board to obtain imprints (Fig. 1). Digital images outlining these rope imprints were then created to serve as the standards (signature maps) with which entanglement wounds could be compared. The initial protocol used to create these standards involved a time-consuming process of manually digitizing an outline of the simulated rope impressions and is detailed in the Fall 2003 edition of ESRI's ArcNews (27). As in the initial protocol, digital photographs were taken of each rope imprint, and imported into Adobe Photoshop®, where they were converted to grayscale and modified to improve the contrast between the rope imprints and canvas backgrounds (27). These modified images were imported into the ESRI ArcMap GIS software. Each pixel in the imported images had a pixel brightness value ranging from 0 (black) to 255 (white). The pixels corresponding to the rope imprints possessed the lowest brightness values. Using the initial protocol, it would take an average of 8 h to manually digitize an imprint. In addition, detecting the black and white interface described in Ref. (27) was occasionally difficult, introducing the potential for analyst error. A more automated approach using image processing tools has been adopted to reduce analyst effort and error.

To create the standards using this new technique, it was necessary to extract only the pixels of images corresponding to the rope imprint. A commonly employed GIS approach for extracting feature information from image data is reclassification, a process in which pixels are grouped into classes. To extract the rope imprint pixels, we used a two-class Jenks optimization approach within ESRI's ArcGIS Spatial Analyst to rapidly explore the image data for a natural break in the distribution of the brightness values of the rope imprint's image (Fig. 2). Because of the inherent contrast in brightness values between the rope imprint pixels and the canvas background pixels, natural breaks proved to be a very effective approach in isolating pixels corresponding to the rope imprint. Using the identified natural break, the image was then reclassified into two classes based on whether or not the pixel corresponded to

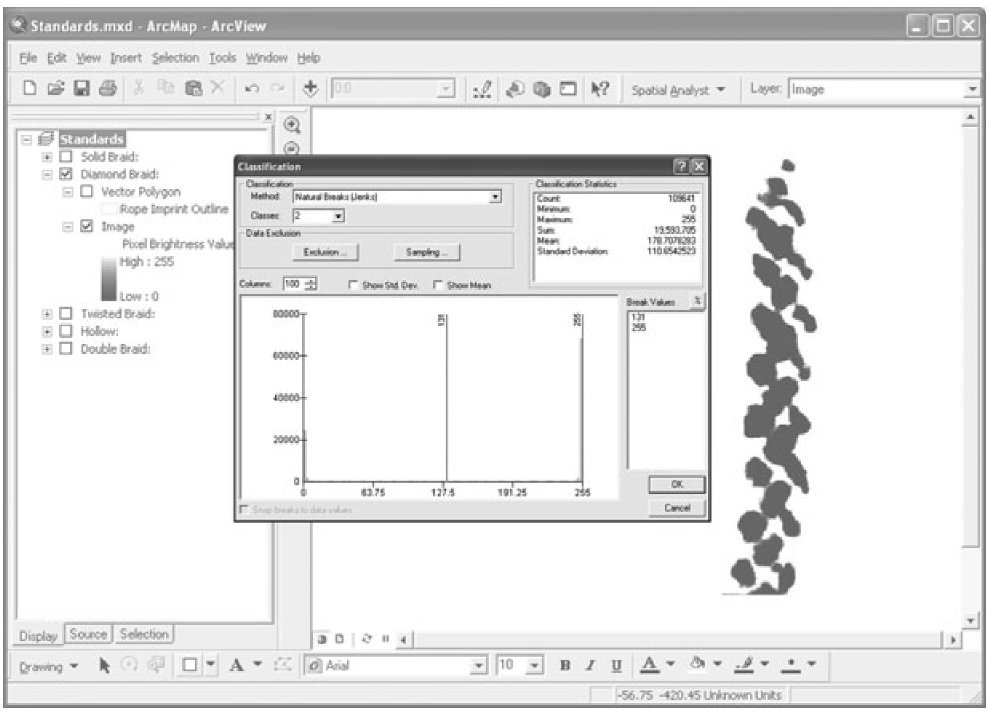


FIG. 2—*Isolation of rope imprint pixels using two-class Jenks optimization approach.*

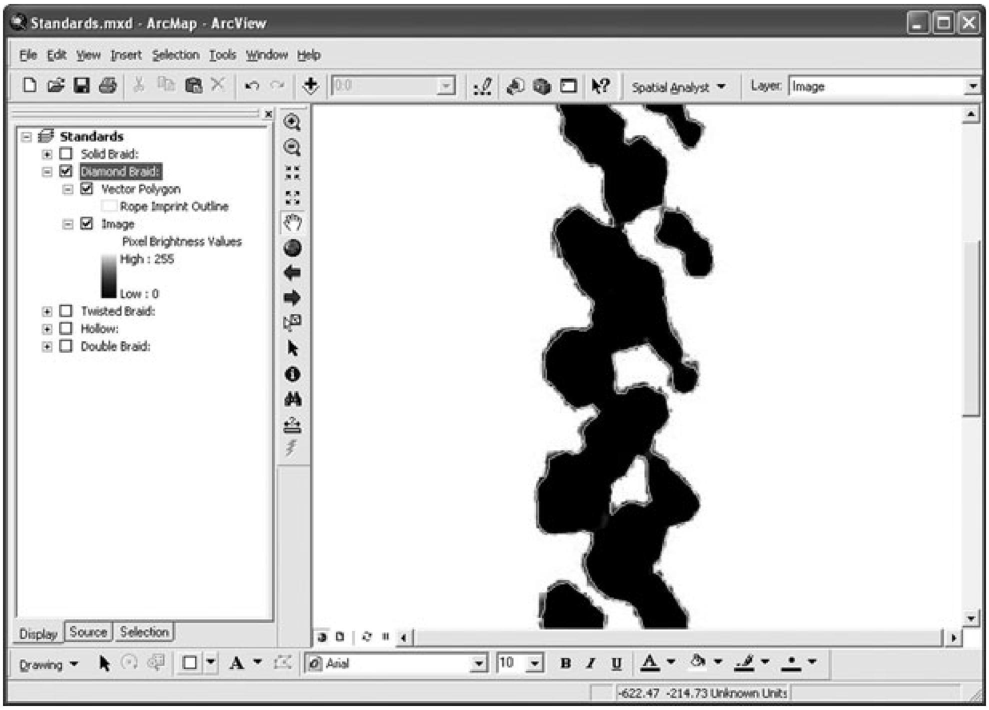


FIG. 3—*Rope imprint image and vector polygon layer used as a standard reference.*

the rope imprint (Class 1) or canvas background (Class 2). The canvas background pixels were subsequently deleted and the rope imprint pixels converted to a vector polygon layer (Fig. 3).

To develop the technique for creating maps from actual entanglement wounds, a request for photographs depicting rope wounds on stranded marine mammal carcasses was made on a marine mammal list server. Digital images and scanned photographs were obtained from 21 contributors, representing 11 countries and 16 species. Each photograph and image was enlarged and cropped to show the greatest amount of detail and converted to grayscale to determine whether the photograph was suitable for analysis. Of the 163 images received, 117 could not be analyzed because of the lack of a scale, absence of visible impression patterns, or insufficient resolution. After visual manipulation in Adobe Photoshop®, photographs that were suitable for analysis were imported into the GIS software for reclassification and

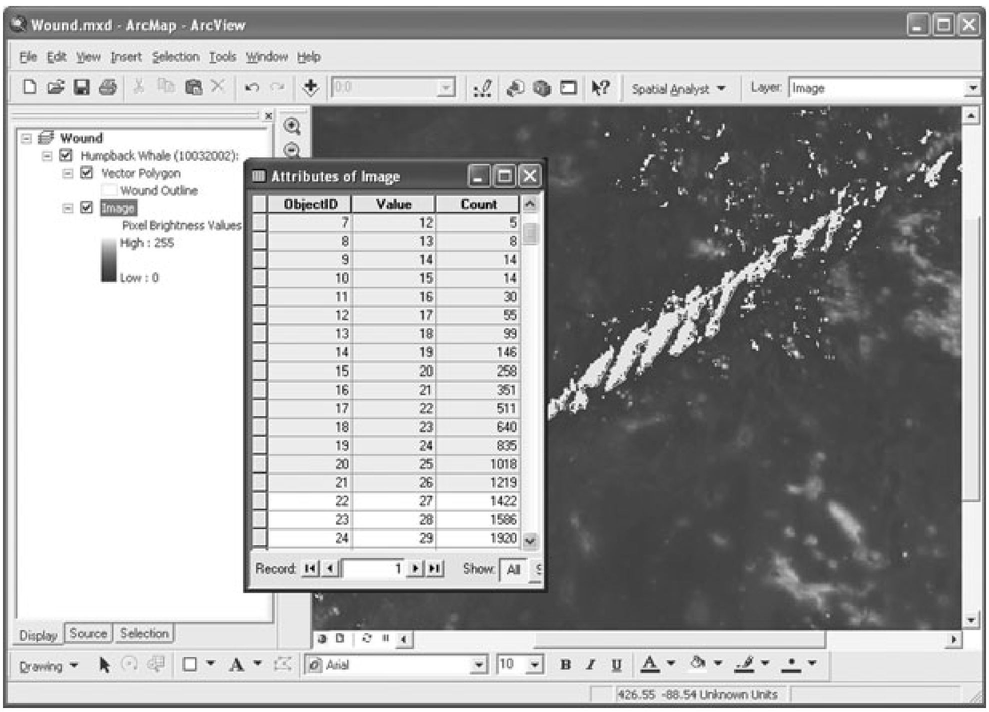


FIG. 4—*Interactive pixel value selection of entanglement image to identify wound pixels. Photo credit: Provincetown Center for Coastal Studies, image taken under NOAA Fisheries permit 932-1489, with authority of the US Endangered Species Act.*

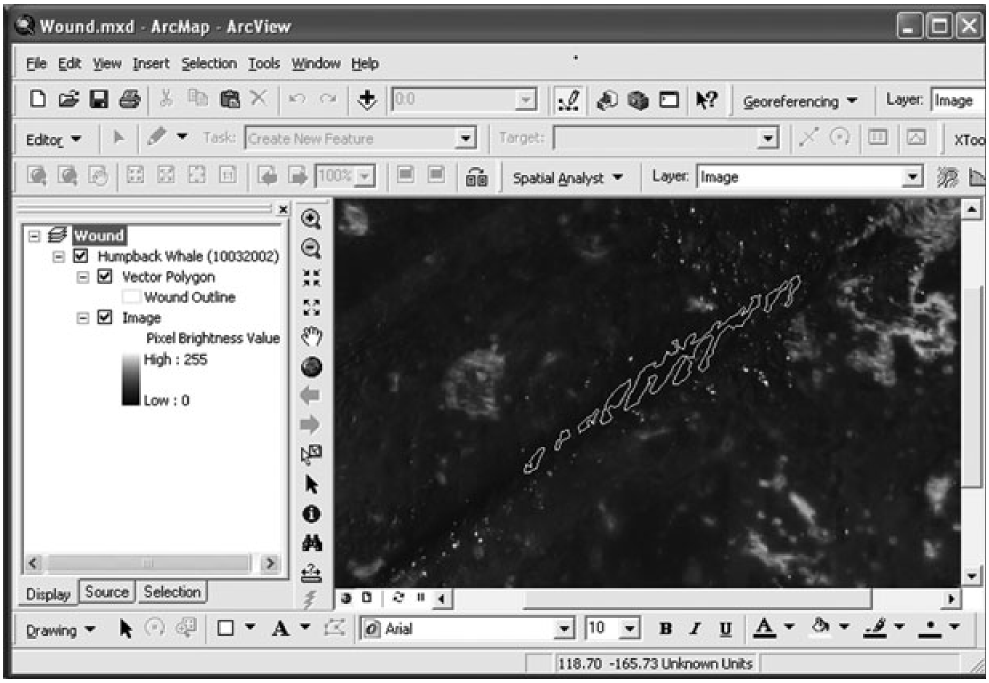


FIG. 5—*Vector polygon developed from an entanglement wound superimposed on original wound image from Fig. 4. Photo credit: Provincetown Center for Coastal Studies, image taken under NOAA Fisheries permit 932-1489, with authority of the US Endangered Species Act.*

polygon creation using the protocol similar to that detailed above for the rope imprints. The distinction between rope imprint and canvas background pixels was fairly significant in the rope imprint images used to create the standards; however, the distinction between wound and nonwound pixels on the images depicting fishery interactions was often very subtle. While the Jenks optimization approach was effective in isolating wound pixels, determining the number of classes to use was an iterative process that had to be performed manually for each entanglement image. We found that isolating the pixels corresponding to a wound in an entanglement image was accomplished much more efficiently by interactively selecting brightness values from the image's attributes table until the appropriate break was located (Fig. 4). Using this break, the image was reclassified and the wound pixels converted to a vector polygon layer. Although manual selection of brightness values required for the entanglement wound photographs, analysts effort and error was reduced from the initial protocol as the image processing tools would automatically create a polygon around the selected pixels. Analyst error was minimized as pixel selection relied on brightness values rather than subjective visual determination. Resulting wound maps were then superimposed onto the original photograph to verify that the wound maps created were true representations of the entanglement wound (Fig. 5).

## Results and Discussion

Knowing the origin of fishery entanglements is critical to the management of marine mammal species (28). The Marine Mammal Protection Act (MMPA, 1972, amend. 1990) was drafted and implemented, in part, to aid in the mitigation of marine mammal and fishery interactions. Regulatory categories were established for fisheries that occupy marine mammal habitats, and the regulations for each category differ in strength dependent upon the level of interaction with a certain marine mammal population (29). These categories serve to guide the regulatory process according to the severity of interaction and the status of the population. The long-term goal of the regulations for each category is to reduce the amount of incidental takes in a fishery to sustain or recover population levels (30). In addition to this categorization, the MMPA established the Take Reduction Process to reduce incidental entanglement in each category. Mitigation methods suggested by the Take Reduction Process include the development of gear modifications, seasonal closures, and other regulations designed by all stakeholders to maintain the economic viability of the fishery while, at the same time, attempting to reduce the entanglement of marine mammals (30). To impose gear modifications and mitigation measures the presence of gear or a method to associate wounds with a particular gear type is necessary. Unless marine mammals strand with fishing gear attached to their carcass, the fishery responsible for a particular entanglement often remains unknown. Developing maps that highlight unique characteristics of fishing gear and entanglement wounds can aid in the identification of marine mammal entanglement sources for animals that strand without gear attached to their carcass, and in the development of appropriate regulations to mitigate future entanglements in those fisheries.

Results of this project show that GIS can be used to develop maps that highlight unique characteristics of fishing gear and entanglement wounds. Image processing tools within GIS provide a semi automated approach to create these maps. This approach is much more efficient and less subjective than the initial protocol of manually digitizing the outline of wound impressions. Now that this pattern comparison technique has been developed, future research will focus on case studies to match unknown entanglement wounds with specific fisheries. Currently, information regarding season, gear type, and location of commercial fisheries along the Atlantic coast is being stored in a database that will eventually be accessible to stranding networks. This database will also include outlines of specific fishing gear that have been developed using the technique described in this paper. The ultimate goal of the database is for stranding networks to be able to identify possible mortality sources for the animals that strand without gear. To do so, members of Atlantic coast stranding networks will be able to compare the location of strandings relative to fishing season and locations, as well as the entanglement wounds to premade standards that are cataloged for the various types of fishing gear. To make this effort effective for stranding networks, entanglement wounds must be properly photographed. The ideal wound images are high-resolution digital, taken at a perpendicular angle to the wound, include a reference scale, and have adequate lighting for differentiating wound characteristics. Many of the photographs that were received for this paper were taken at too great a distance to identify wound traits, or were not at a 90° angle to the wound. Also, scanned photographs often became pixilated when the image was manipulated in Adobe Photoshop®. The success of this forensic tool is dependent on the quality of photographs received from the researcher, as well as the development of a database of gear types and fisheries that occupy marine mammal habitats.

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Additional information and reprint requests:
Leslie Burdett, M.S.
Biologist
219 Fort Johnson Rd
Charleston, SC 29412
E-mail: leslie.burdett@noaa.gov