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Automating Image Matching, Cataloging, and Analysis for Photo-Identification Research

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Abstract

The expanding use of digital photography for marine mammal photo-identification has created a need for tools to analyze and manage growing image file archives. While database management systems have been commonly employed to manage text and numerical data generated by photo-identification research, their use for the analysis and management of associated image files has been limited. This paper describes a photo-identification database management system with embedded image analysis and management capabilities. Matching and cataloging are expedited using a multiple-attribute, non-metric catalog sorting algorithm. Algorithm efficiency at locating catalog matches for bottlenose dolphins was compared to the performance of a more traditional single-attribute, non-metric approach. Locating catalog matches under the multiple-attribute approach required at least 50% fewer comparisons for 90% of the 409 individuals tested. For 50% of the individuals, 80% fewer comparisons were required. System utility is further extended through embedded mapping components that allow researchers to visually inspect sighting locations following each survey and to examine sighting histories for specific individuals. In addition, a companion *ArcGIS*™ extension allows researchers to quickly explore and interact with the photo-identification data within a GIS environment. This system, while created for a bottlenose dolphin research application, can be adapted to accommodate photo-identification research on a variety of other species.

Key Words: Photo-identification, non-metric, database management system, digital images, bottlenose dolphin, *Tursiops truncatus*

Introduction

Photo-identification of marine mammals using natural markings has been widely applied to monitor populations (Wells & Scott, 1990; Würsig & Jefferson, 1990; Langtimm et al., 1998; Blackmer et al., 2000; Vincent et al., 2001). The advent of digital photography advanced photo-identification methodology by enhancing the quality of images, facilitating the electronic storage and management of images, and allowing researchers to develop computer-assisted techniques to expedite the matching process. Concurrently, database management systems have increasingly been employed to store and manage text and numerical data associated with photo-identification research. While database management systems are well-suited to handle the management and analysis of digital images, these tasks often are performed outside of the system. The following describes a system developed for bottlenose dolphin (*Tursiops truncatus*) photo-identification research that incorporates image management and analysis capabilities, data visualization capabilities, and a non-metric, multiple-attribute catalog sorting algorithm to expedite the matching process. The efficiency of the multiple-attribute catalog sorting algorithm in locating catalog matches was compared to the efficiency of matching under a more traditional single-attribute approach. While the system was tailored for bottlenose dolphin research, it can be adapted for use with a variety of other species.

Computer-Assisted Matching

Computer-assisted matching techniques can be categorized as either metric or non-metric in approach. Metric-based approaches use metrical analyses calculated on features such as dorsal fin notches, fluke markings, or coloration patterns (Hiby & Lovell, 1990; Whitehead, 1990; Huele & de Haes, 1998; Hillman et al., 2003; Kehtarnavaz et al., 2003; Arzoumanian et al., 2005). Metric techniques require the photo-analyst to either manually digitize fin features from images of individuals or provide some degree of assistance to a semi-automated digitization process. Potential catalog matches are then searched by using information extracted during the digitization process; however, metric-based techniques can be sensitive to image quality (Beekmans et al., 2005). Elements of image quality that can have the greatest impact include camera angle and the relative size of features or markings in the image (Whitehead, 1990; Hillman et al., 2003; Markowitz et al., 2003).

Non-metric, computer-assisted techniques use categorical descriptions of features (e.g., spots, rakes, fluke pattern, upper notch, lower notch, etc.) to assist in the matching process (Mizroch et al., 1990; Yochem et al., 1990; Harting et al., 2004; Mazzoil et al., 2004). Feature information, such as an upper fin notch and/or middle fin notch, observable on an image(s) of an individual, is identified by the photo-analyst and typically stored in a database. This feature information is subsequently used by the photo-analyst to search for potential catalog matches when new images of individuals are collected. Non-metric approaches may not be as dependent on image quality as their metrical counterparts.

The Charleston Dolphin Photo-Identification Study

A photo-identification study of bottlenose dolphins has been ongoing in the Charleston, South Carolina (32° 47' N, 79° 56' W) area for over 10 years with the objective of identifying the resident status and population size of Charleston area bottlenose dolphins. Methodologically modeled after earlier photo-identification studies (Defran et al., 1990; Urian & Wells, 1996), the fin catalog was partitioned into a series of binders containing hardcopy images of individuals sharing a designated predominant dorsal fin feature or a common number of notches. For example, a "chop" category was used to classify dorsal fins that could be distinguished by a missing top portion. Additionally, the trailing edge of the dorsal fin was divided into thirds, and fins with a distinguishing notch were classified as an "upper," "middle," or "lower" marked fin. Other categories included "apex" (nick/mark on tip of dorsal fin), "lead" (nick/notch on leading edge of fin), "bend" (dorsal fin bends to right or left), and a miscellaneous category which included any individuals for which the distinguishing features was on a part of the body other than the dorsal fin.

Over the years, the survey area and effort for the Charleston dolphin study gradually expanded, as did the size of the photo-identification catalog: from the original 112 individually identified dolphins (Zolman, 2002) to over 1,000 individuals. Furthermore, the extensive study period also resulted in numerous resights of many individuals. Because an image is saved for each individual in each sighting, a large number of images (> 10,000) accumulated.

In 2002, our program made the transition from conventional film to digital images, and the series of binders representing the Charleston photo-identification catalog was replaced with computer folders. Initial examination and sorting of field images were accomplished using *Adobe Photoshop* digital imaging software (Markowitz et al., 2003; Mazzoil et al., 2004). At first, the underlying classification scheme (i.e., partitioning based on a single predominant fin feature) did not change. While this type of classification scheme was suitable when our catalog was small, it proved to be relatively inefficient as our catalog grew to include hundreds of entries sharing the same predominant dorsal fin feature. As the transition to digital images provided the basis for the automation of a number of tasks associated with the photo-analysis process, we sought to more fully exploit the broad range of automation opportunities.

In lieu of the traditional method of partitioning the catalog into categories based on a single predominant dorsal fin feature, a system was designed to maintain a catalog of bottlenose dolphins in which individuals can possess any number of additional attributes. While these additional attributes might not be considered distinguishing features on their own, they add supplementary information that leads to a more unique fin description. Similar approaches have been developed for the identification of humpback whales (*Megaptera novaeangliae*) and Hawaiian monk seals (*Monachus schauinslandi*); however, we found no published procedure using a multi-attribute approach for bottlenose dolphin identification (Mizroch et al., 1990; Harting et al., 2004). The system described herein contains 20 attributes that can be used to characterize individuals. As a new individual is entered into the catalog, the photo-analyst identifies the attributes which best characterize the new entry (Figure 1). Priorities indicating the relative importance of each attribute for the identification of the individual are also defined. A catalog sorting algorithm was subsequently developed to take advantage of the multiple-attribute system. This algorithm sorts the entire catalog based on search attributes and priorities provided by the photo-analyst. The following describes the system and the catalog sorting algorithm. The performance of the algorithm is compared to that of a more traditional single-attribute, non-metric approach.

Materials and Methods

The FinBase System

A database system designed to facilitate data entry and analyses, expedite the matching and cataloging processes, and reduce errors associated with manual image file management was developed. *FinBase* is a *Microsoft Access* database customized using *Microsoft Visual Basic for Applications* (VBA) that utilizes a third-party ActiveX control (Atalasoft© ImgX, Northampton, Massachusetts, USA) to provide digital image analysis functionality. In *FinBase*, many of the tasks associated with data entry, photo analysis, and data visualization were automated using a collection of customized database forms with user-friendly interfaces. With some minor modifications to the design of the forms and the underlying VBA code, the system can be adapted to accommodate photo-identification research being conducted in other locations and with a variety of other species.

The primary forms associated with data entry include the Survey and Sighting forms (Figure 2). Both were designed to closely mimic their field data sheet counterparts to facilitate data entry and verification. Data entered on the Survey form include survey number (automatically generated by database), survey type, survey area, survey completion status, survey hours (computed using worksheet located on back of survey field data sheet), distance traveled during survey (computed using worksheet located on back of survey field data sheet), and names of the survey's downloaded trackline and waypoint GPS files. *FinBase* uses the identified waypoint file to automatically extract latitude and longitude coordinates associated with survey and sighting data. Sighting data are recorded each time an individual or group of bottlenose dolphins are encountered during a survey. Data entered and verified on the Sighting form include sighting number, survey effort (on or off) at time of sighting, survey platform, field crew members, location information, sighting conditions, field estimates, observations and behaviors, camera and/or camcorder information, and sighting notes.

The primary forms associated with the photo-analysis process include Catalog Search, Match Fin, New Fin, and Clean Fin forms. The Catalog Search form (Figure 3) allows users to search the existing catalog for matches to individuals photographed during a sighting. Individuals in the catalog are presented to the user in a sorted order based on a collection of fin attributes that the photo-analyst identifies for the individual under scrutiny. The catalog sorting algorithm is discussed in the "Materials and Methods" section. If the Catalog ID of the sighted individual is known, users can bypass calling up the entire catalog by selecting the Catalog ID option found in the Catalog Search Criterion frame and entering the known individual's Catalog ID. If the fin features are distinct enough to identify the individual, but not distinct enough for identification in future sightings, the Clean Fin option is selected in the Update Database frame in the upper-right corner of the form. This opens the Clean Fin form (Figure 1), which is used to process unmarked individuals. If a search is performed and a catalog match is identified, the user selects the Match Fin option, which opens the Match Fin form (Figure 1). If a

Figure 1. *FinBase* forms used to process sighted individuals; unmarked individuals distinct enough to identify within the sighting are processed using the Clean Fin form (front), marked individuals currently not in the catalog are processed using the New Fin form (middle), and resights of cataloged individuals are processed using the Match Fin form (back).

catalog match is not identified, the New Fin option is selected, which opens the New Fin form (Figure 1). The Match Fin and New Fin forms perform database edits and image file management tasks associated with processing resights and first sightings of individuals, respectively. Images are renamed and relocated to reflect the catalog match or a new catalog entry. For new fins, a unique Catalog ID is generated for the individual based upon the photo-analyst-specified catalog series.

Forms associated with data visualization include the FinBase Map form and the FinBase Mapping Tool (Figure 4). Visualization of photo-identification data provides a means by which location data can be verified and spatial relationships between individuals and the environment can be characterized and communicated. The FinBase Map form allows users to visually inspect sighting locations following each survey and examine sighting histories for specific individuals. In addition to generating these "quick-looks" of sighting locations for surveys and catalog individuals, the embedded mapping functionality also allows users to easily generate reports containing maps of individual

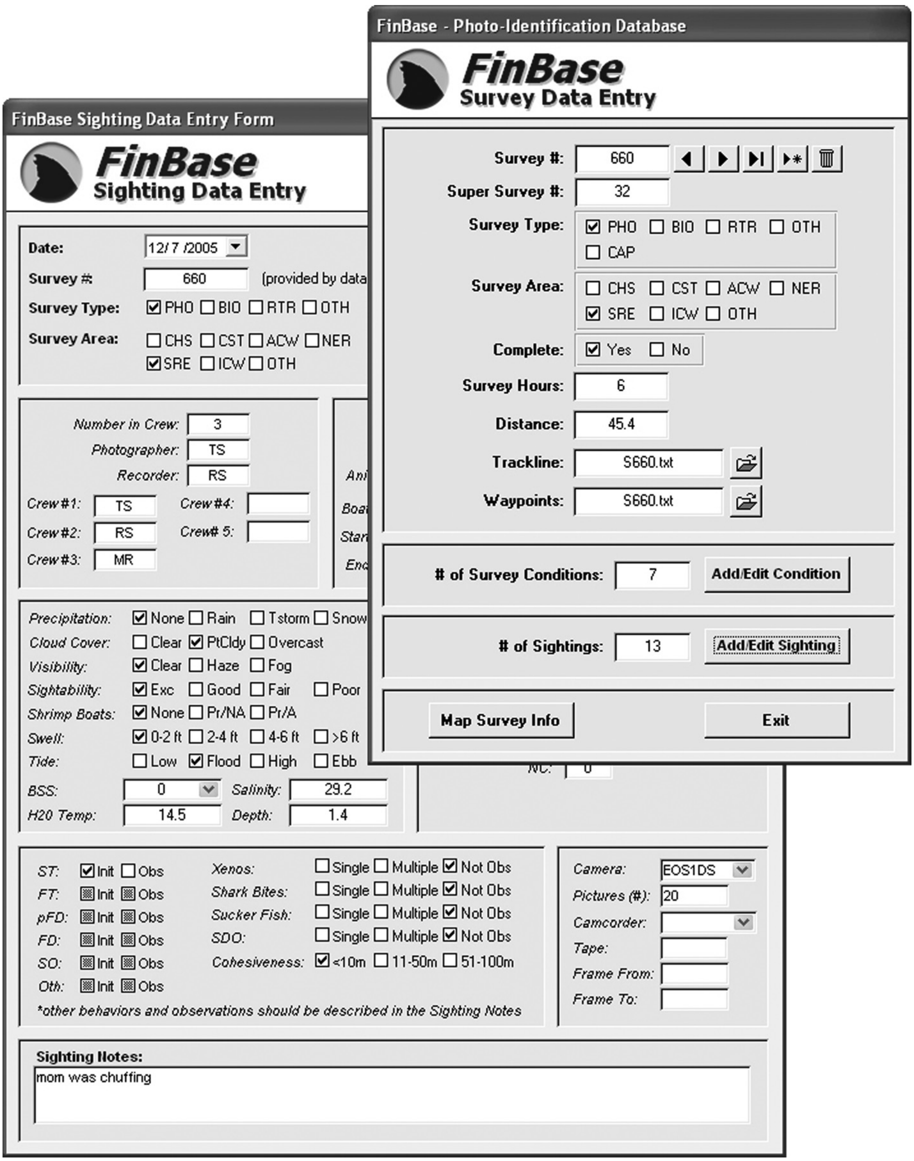

Figure 2. *FinBase* forms used to enter survey (front) and sighting (back) data

sighting histories for a given subset (or the complete set) of cataloged individuals. The *FinBase* Mapping Tool, an *ArcGIS*™ extension, was developed to allow users to explore more complex research questions from within ESRI's *ArcView GIS* software. Users with little to no background in GIS or relational databases can query *FinBase* on variables such as weather, water depth, tide, observed dolphin behaviors, and boat presence using simple, point-and-click controls. Results from these queries are spatially displayed within the *ArcView* data frame.

Other *FinBase* forms of note include the Catalog Browser and Photo Analysis forms. The Catalog Browser form (Figure 5) allows users to view the sighting history, social associations, and all right and left dorsal fin images stored in *FinBase* for a cataloged individual. The Photo Analysis form (Figure 6) provides information regarding the results of the photo analysis associated with each sighting. Information provided includes an accounting of individuals associated with the sighting and revised estimates of group size, including number of neonates and calves.

Catalog Sorting Algorithm

After a survey, field data are entered into *FinBase* and digital images are sorted. The photo-analyst is then ready to search for catalog matches using the Catalog Search form (Figure 2). In this form, the photo-analyst browses to the directory of sorted image files and selects the first image to be processed. Basic image analysis functions, such as zoom and pan, can be used to examine the imported image. The photo-analyst selects the appropriate attributes to use for the catalog search. The number of search attributes, *n*, can range from 1 to the total number of available attributes (N). Priorities are assigned to the attributes based on the order in which the user selects them and will impact the manner in which the catalog is sorted. An existing catalog individual's position within the sorted catalog is based on the similarity of its attributes to the set of selected search attributes. Specifically, an individual's catalog position is determined using the following five criteria, listed in order of importance:

Criterion 1. Number of attributes matching the search attributes

Criterion 2. Number of additional attributes held by the catalog individual not specified as a search attribute by the photo-analyst

Criterion 3. Priority of search attributes matched with the individual's attributes

Criterion 4. A calculated weighted-difference score (S_{wd}) for the individual:

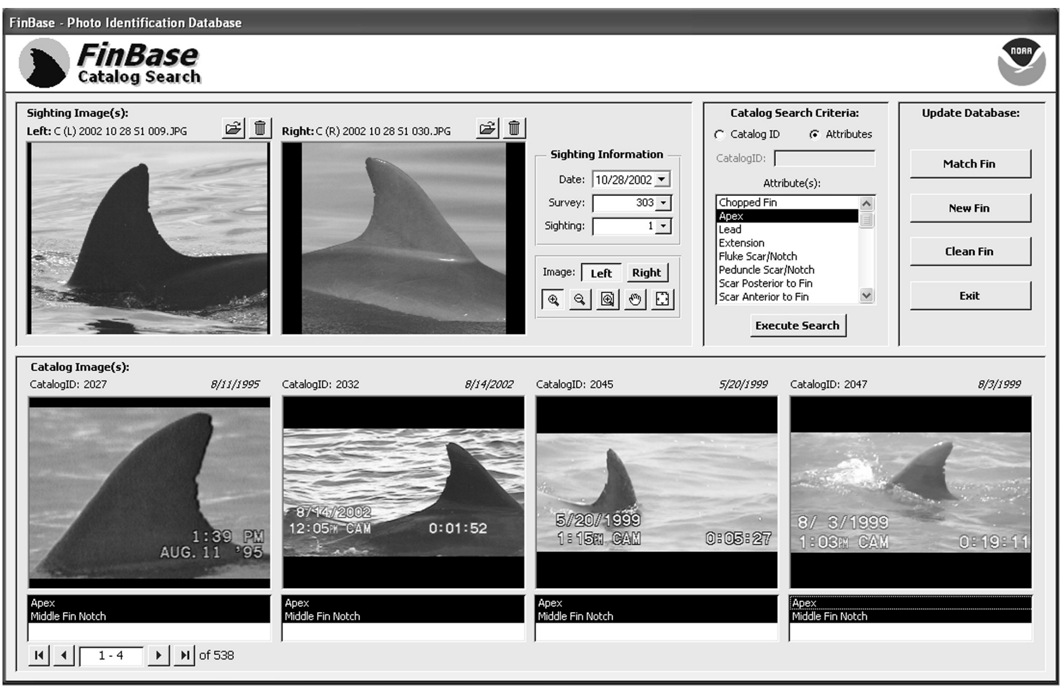

Figure 3. *FinBase* form used to conduct catalog searches for sighted individuals

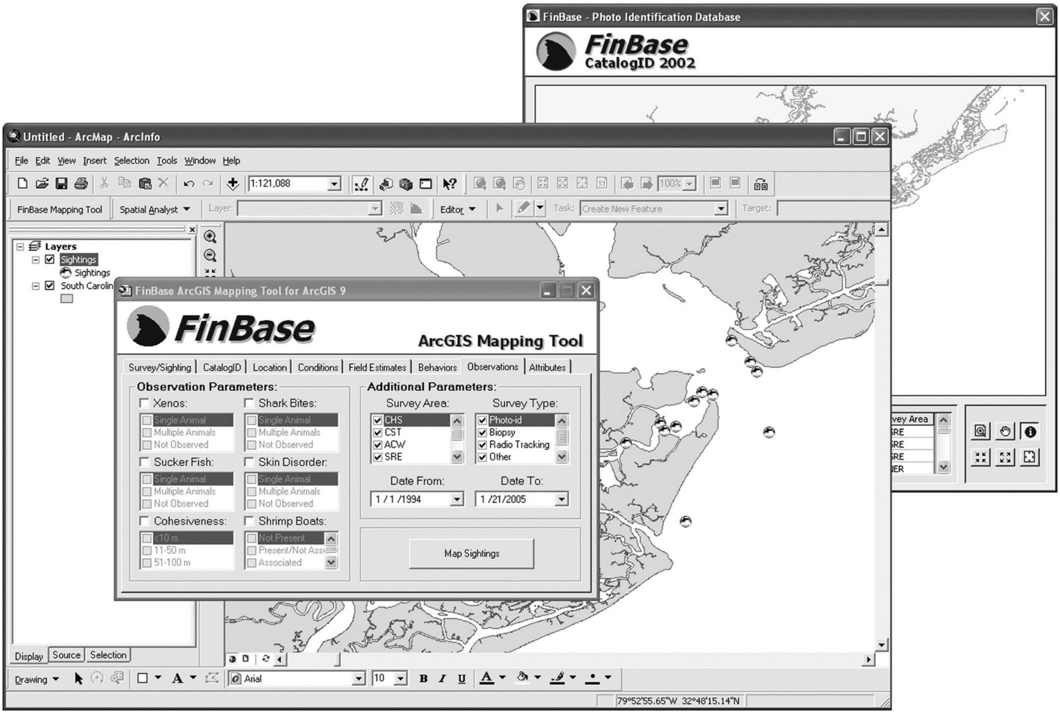

Figure 4. *ArcGIS*™ Mapping Tool (front) and *FinBase* form (back) used to facilitate the visualization of sighting distributions of cataloged individuals

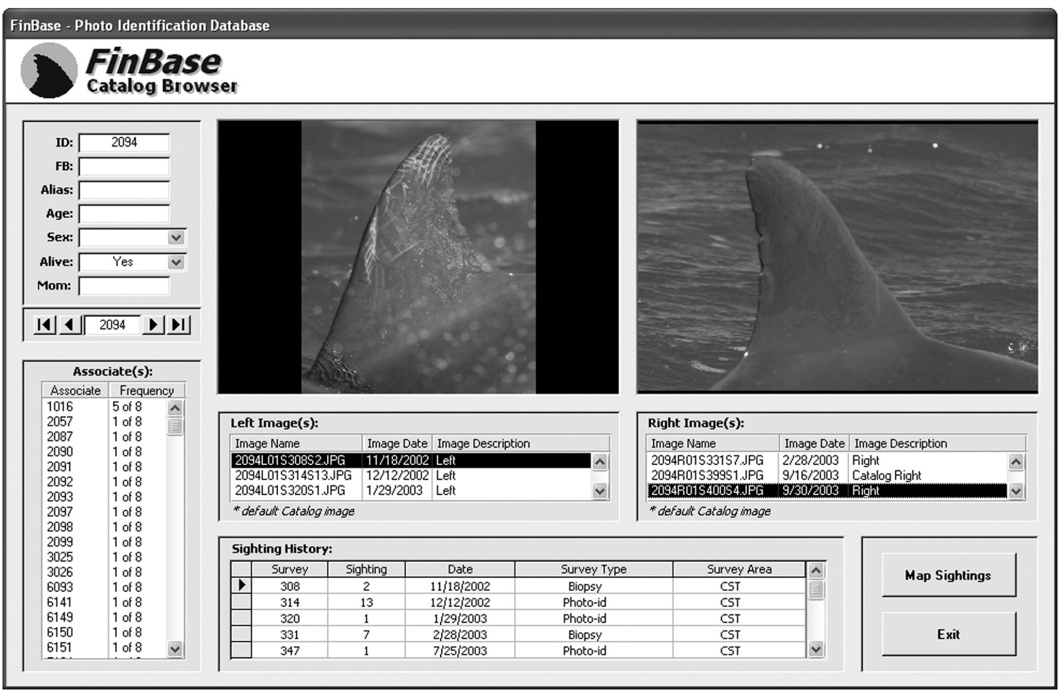

Figure 5. *FinBase* form used to reference sighting history, photo inventory, and associates of cataloged individuals

$$S_{wd} = \sum_{i=1}^{n} (n\text{-}(Priority_{Search}\,(i) - 1))^2 * Priority_{Individual}\,(i)$$

where,

S_{wd} = weighted-difference of individual's assigned priorities with the user-specified priorities of the search attributes,

n = number of user-specified search attributes,

$Priority_{Search}\,(i)$ = user-specified priority for search attribute i, and

$Priority_{Individual}\,(i)$ = catalog individual's assigned priority for search attribute i.

Criterion 5. Catalog ID (Individuals with lower Catalog ID are positioned closer to the beginning of the sorted catalog.)

If individuals within the catalog share the same value for Criterion 1, their sorted positions are determined using Criterion 2. If they also share the same value for Criterion 2, positions are determined by Criterion 3 and so on through Criterion 5.

Partitioning catalogs using only a single predominant fin feature is a common approach adopted by research laboratories conducting photo-identification research on bottlenose dolphins. To evaluate the performance of the multiple-attribute approach used by *FinBase*, the number of image comparisons required to match each individual within

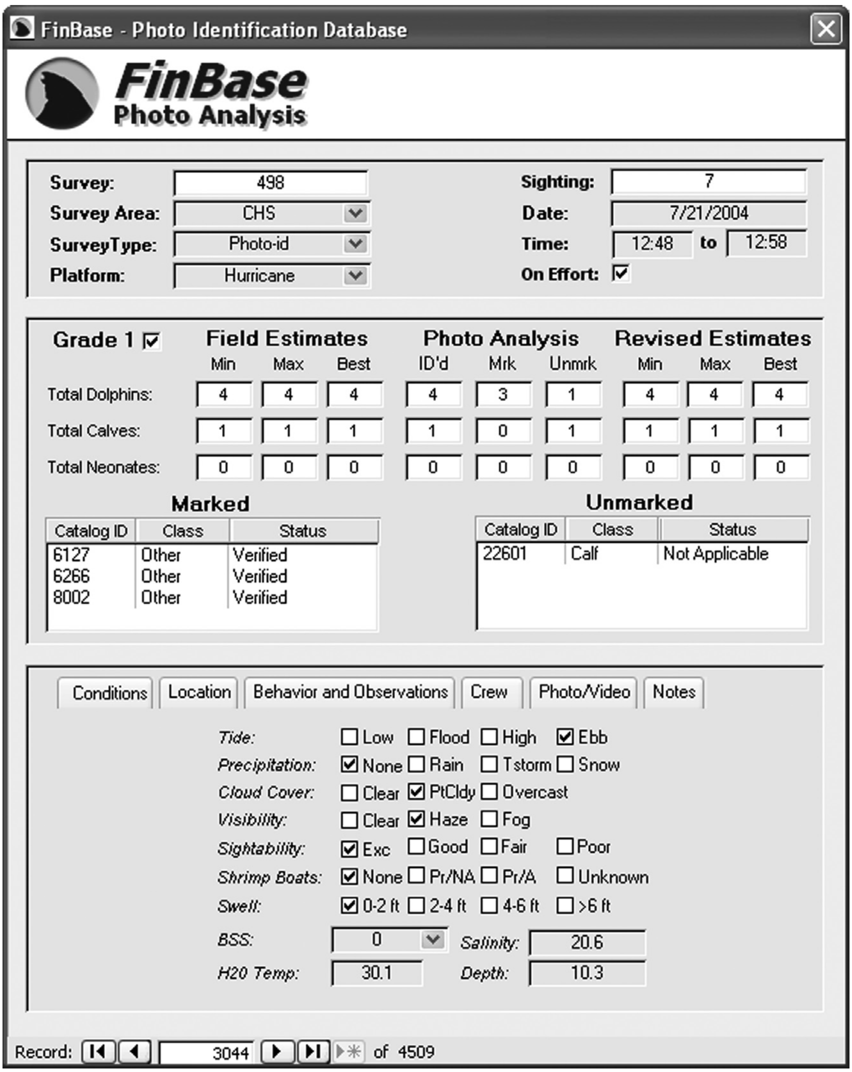

Figure 6. *FinBase* form used to verify field data and photo-analysis results

our photo-identification catalog was determined using both single- (i.e., predominant fin feature) and multiple-attribute approaches. A performance ratio was calculated by dividing the number of image comparisons required using the multiple-attribute by the number of comparisons required using the traditional single-attribute approach. The performance analysis was conducted using a subset of 409 individuals from the Charleston catalog, 48% of which had been assigned two attributes, and 38% of which had been assigned three or more attributes (Figure 7). A search was conducted for each of the 409 individuals using both the single- and multiple-attribute approaches. For the single-attribute approach, it was assumed that the photo-analyst would be able to properly identify the single predominant dorsal fin feature and, consequently, reference the appropriate catalog category. For the multiple-attribute approach, it was also assumed that the photo-analyst could correctly identify the predominant dorsal fin feature, which would serve as the highest priority attribute. It was also assumed that the photo-analyst would be able to correctly identify any additional attributes recorded for an individual when sorting the catalog using the multiple-attribute approach. It was not assumed, however, that the photo-analyst would correctly identify the priorities associated with the additional attributes, and these priorities were generated randomly from the set of all possible permutations.

Results

As an example of the performance analysis, the individual pictured in Figure 8 would be a member of the middle fin notch catalog category under the single-attribute approach. Under the single-attribute approach, a photo-analyst would need to review the images of 43 individuals before arriving at the recaptured individual (44th out of 86) within the middle fin notch catalog category. However, because of the individual's unique combination of fin attributes, the multiple-attribute approach results in the recaptured individual being placed at the first position in the catalog, when sorted using an attribute search combination of middle fin notch, lower fin notch, and skin disorder. The performance ratio

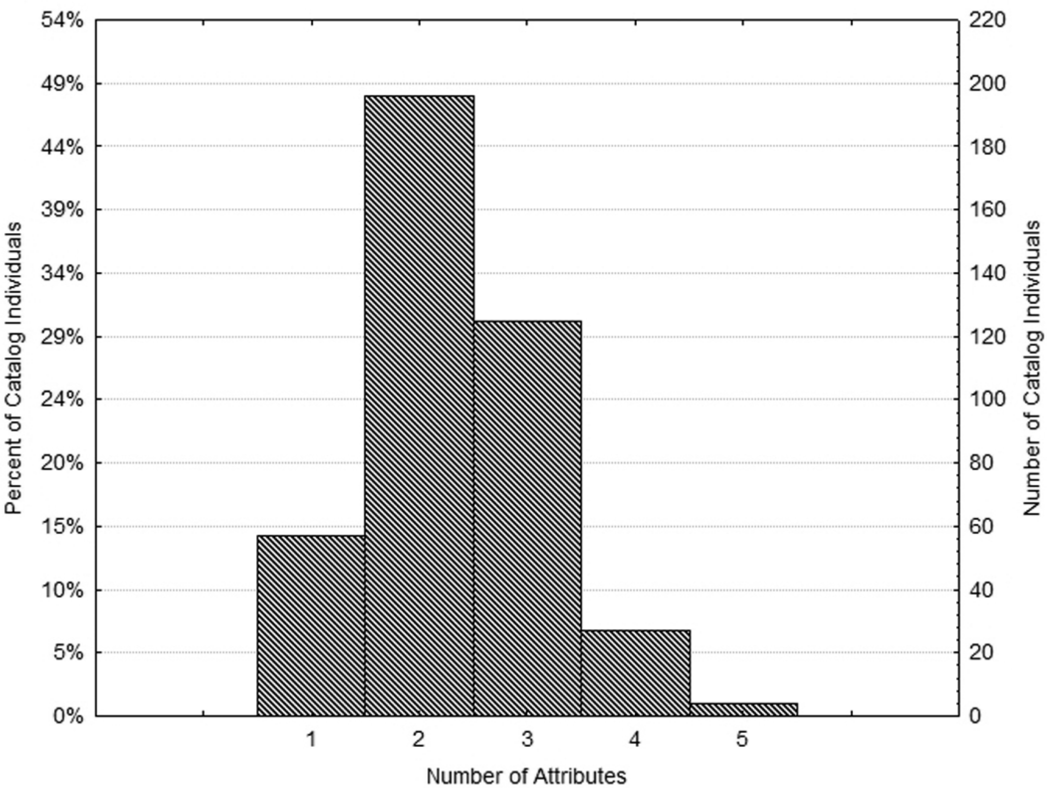

Figure 7. Number of fin attributes stored for bottlenose dolphin in the Charleston, SC, photo-identification catalog

for the above example would be 0.023. While the results of the performance analysis were not this dramatic for each individual, the multiple-attribute approach repeatedly outperformed the single-attribute approach (Figure 9). For 90% of the catalog searches, the multiple-attribute approach required at least 50% fewer comparisons than the single-attribute approach (performance ratio ≤ 0.5), and for 50% of the searches, at least 80% fewer comparisons were required (performance ratio ≤ 0.2). In only 1% of the searches (6 out of 409) did the single-attribute approach require fewer comparisons than the multiple-attribute approach.

Conclusions

Providing the tools to quickly explore and interact with photo-identification data allows researchers more time to develop and evaluate more informed research questions. As research programs make the conversion from analog to digital catalogs, researchers are confronted with the task of managing image archives. Manual management of image files and the use of an outside image viewing software package to match and catalog fins can lead to error and inefficiencies. *FinBase* exploits the move to digital photography and the available functionality of database management systems

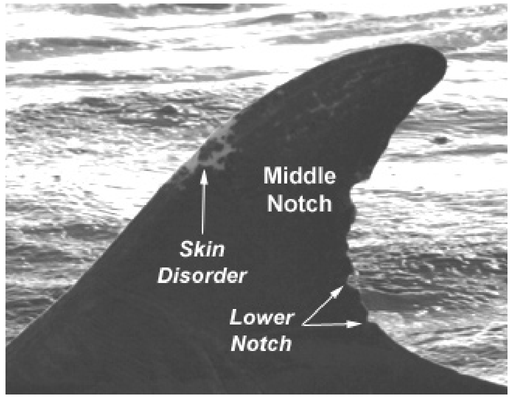

Figure 8. Fin attributes (middle notch, lower notch, and skin disorder) entered into *FinBase* for Catalog ID# 7087 in the Charleston, SC, bottlenose dolphin photo-identification catalog

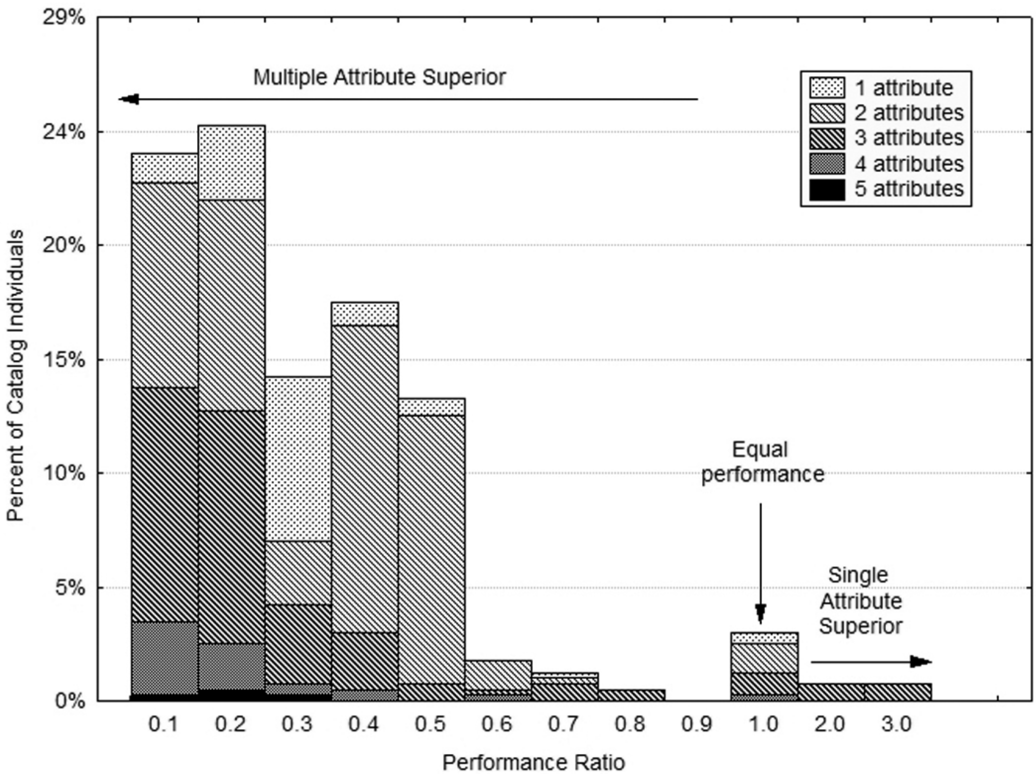

Figure 9. Performance of single- and multiple-attribute catalog searches for bottlenose dolphin (n = 409) in the Charleston, SC, photo-identification catalog; performance ratio is the number of comparisons required using the multiple-attribute approach divided by the number of comparisons required using the single-attribute approach.

by embedding image management, analysis, and processing directly into the photo-identification database. Similar non-metric catalog matching approaches have been described for other marine mammal species, but *FinBase* is the first system to provide a non-metric approach for bottlenose dolphins. In addition, other computer-assisted matching tools, metric and non-metric, often exist outside of the photo-identification database. *FinBase* represents an integrated photo-identification database in which assisted matching and cataloging of dorsal fin images are expedited, automated, and occur inside of the photo-identification database. The integration and automation of these tasks not only reduces the time and effort required from the researcher, but also eliminates user error associated with manual image file management. However, the fin attributes used to characterize an individual in the catalog is a relatively subjective determination made by the photo-analyst processing the entry. As a result, attribute assignments may vary among photo-analysts. For example, what one photo-analyst deems to be an upper fin notch may be defined as a middle fin notch by another photo-analyst. In addition, similar discrepancies may occur when designating priorities to assigned attributes. Current research is focused on incorporating a metric search component to complement the multiple-attribute catalog search algorithm.

The Charleston dolphin study has benefited significantly from the development and integration of *FinBase* for image management and automation of the photo-analysis process. As our catalog continues to expand and we bring in new research personnel, we find that automation of image processing and management, and the simplification that it brings to our laboratory procedures, is extremely important for effectively maintaining the ever-growing body of information and images.

The database system, along with a small sample dataset, is available free of charge to interested research programs (contact first author). Table structures and their underlying VBA codes are accessible, allowing the database to be modified to accommodate photo-identification research being conducted in other locations and with a variety of other species. Use of the system requires a version of *Microsoft Access* to be installed on the host computer, and modification requires some basic VBA programming skills.

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