

NON-METRICAL DIGITAL PHOTO- IDENTIFICATION SYSTEM FOR THE HAWAIIAN MONK SEAL

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Photographic identification is an increasingly important tool in population assessment (*e.g.*, Mizroch *et al.* 1990, Whitehead 1990), behavioral research (Kaufman *et al.* 1990, Morton 1990, Shane and McSweeney 1990, Whitehead 1997), and foraging studies (Katona and Beard 1990). With the advent of inexpensive high-resolution digital cameras and powerful image processing software, digital imagery has largely supplanted traditional emulsion film for most photo-based research. Because digital imaging is relatively new to wildlife research, many biologists are not well acquainted with the options available for managing their images.

The ease with which digital images can be acquired enables huge image databases to be assembled in a fairly short time: the accumulation of thousands of images in a single field season is not uncommon. A challenge is to properly catalog and manage those images to fully exploit their many advantages. Manually reviewing large image libraries to compare records and matching new images to those stored in the image library is cumbersome and inefficient. When the features used to distinguish individuals are well defined or morphologically localized, it is possible to develop custom algorithms and dedicated software to automate the labor-intensive tasks of inspecting and matching images. These computer-assisted methods typically rely on metrical analysis of distinct features. Examples include measuring the dorsal ratios of fin notches or other irregularities on the dorsal fin of dolphins (Kreho *et al.* 1999, Araabi *et al.* 2000, Hillman *et al.* 2003, Markowitz *et al.* 2003), analyzing the pattern of marks on the edges of sperm whale flukes (*Physeter macrocephalus*; Whitehead 1990), or analyzing coloration patterns on the heads of gray seals (*Halichoerus grypus*; Hilby and Lovell 1990). Photo-identification may also utilize non-metrical features visible on the animal, such as scars and general pelage patterns (*e.g.*, Yochem *et al.* 1990, Forcada and Aguilar 2000).

While image recognition technology is ideal for certain studies, it may be less suitable when a suite of morphological traits distributed about the body is used to identify individuals. First, different algorithms would be required for each body region that bears distinguishing traits. Further, some features are not amenable to algorithmic reduction (*e.g.*, scar patterns that contrast weakly with the surrounding pelage) and would require a major investment, not only to develop diagnostic algorithms, but also to verify that the resultant algorithm(s) behaved as expected with each new image. In such cases there appears to be little alternative to manual inspection of candidate images.

We recently instituted a system for managing digital images of the endangered Hawaiian monk seal (*Monachus schauinslandi*). This comprehensive system can search the entire library to quickly find images that match specified search criteria. While this system was designed specifically for the monk seal, many components of the system should be applicable to research with other species that use non-metrical features to distinguish individuals.

Many components of monk seal population assessment depend on the ability to distinguish individual seals, for example determination of demographic rates (survival and fecundity), interatoll migration rates, and population age/sex composition. Three primary methods are used to identify individual seals: flipper tags, applied pelage bleach marks, and natural marks. Since the mid-1980s, most young-of-the-year have been given plastic tags on each rear flipper, and seals not tagged as pups were often tagged in subsequent years. The effective lifespan of the tags varies considerably among individuals, but tags may be readable for up to 15 yr after they are attached. Seals with deteriorating (or lost) tags are periodically retagged, but this effort requires a suitable field context and sufficient field personnel to restrain and tag seals.

Despite the emphasis placed on tagging, many seals remain untagged and must be identified exclusively by natural features. The features most commonly used to distinguish individuals are scars of various types and "natural bleaches" (contrasting areas of light natural pelage), but other features are occasionally used, *e.g.*, an unusual teat arrangement.

Until recently, the primary means for describing these natural features, and later matching them to identify seals, was through hand-drawn "scar cards" supplemented by photographic film images taken during previous seasons. For each seal, prominent scars and other markings were recorded on the cards, with features updated annually as a seal's appearance changed. When an unidentified seal was observed, researchers manually searched among the existing cards to find one that best matched the observed features.

Reliance on hand-drawn scar cards was cumbersome and imprecise. A major difficulty with the hand-drawn scar cards was the unwieldiness of manually inspecting large numbers (perhaps hundreds) of cards or photographs to find matches. The total number of cards in the scar card database at each site depended on the number of seals in the subpopulation (from 64 to 290 seals at the six main breeding atolls), and the number of cards available for each seal (up to 10–20 cards for some of the older seals). A new card was prepared annually for each seal, but

because not all perspectives were redrawn each year, the older cards sometimes contained indispensable information and would need to be reviewed during the matching process.

Depending on how much information was acquired for an unknown seal (e.g., sex and tag status), it was often necessary to browse through many separate file boxes of cards and photo albums. For example, at the most populous breeding atoll, French Frigate Shoals, if the sex of an unidentified adult seal was unknown, it was necessary to manually inspect the current and historical cards for all 165 adult seals known to occur at that atoll. Yet another formidable problem involved variability among observers in how they depicted the same features. It was not uncommon to devote an hour or more in a search for an unknown seal, only to discover later that variability in how observers rendered a distinguishing mark impeded the ability to match an animal.

These inefficiencies had the potential to result in misidentification or loss of identity for individual seals. Each season, individuals lacking highly distinctive markings presented considerable difficulty in ascertaining and maintaining their identity. These seals were often treated as "non-unique" (that is, they were not counted in the population total due to the inability to subsequently recognize them as the same seal). We also suspect that the identity of some of the more challenging *permanently identified* seals was not established in all seasons. Although the extent of these errors is not directly quantifiable (and a number of contingencies safeguarded against misidentification), the sometimes tenuous nature of the identification thread for unknown seals was a legitimate concern, especially with regards to calculating age-specific survival and reproductive rates.

The digital imaging system developed for Hawaiian monk seals consists of six major components: (1) acquiring digital images using digital cameras, (2) renaming files according to standard protocols and annotating the images, (3) organizing the images into a logical directory structure, (4) assigning "Key Indexes" (morphological descriptors to serve as search criteria) to the images, (5) maintaining an efficient image database (minimizing the size by archiving redundant images), and (6) backup and quality control.

The power of the digital imaging system lies primarily in item (4): associating specific search criteria with each image to facilitate matching images stored in the database to features seen on an unknown seal. Nonetheless, a comprehensive system for managing digital images must include provisions for each component listed above. Some components, such as the need for a logical directory structure, might appear so obvious as to not warrant mention, but these are explicitly listed here to emphasize that each element of the system merits forethought. For example, the relationship between item (3) (directory structure) and item (4) (search criteria) has a real bearing on the efficiency of searches within the image library.

Acquisition of the Digital Images

The first step in managing a digital database is initial acquisition of the images, including registering (on data forms) the image number and other pertinent

information as the images are collected. It is important to use the same number on field forms as that assigned by the camera (and visible in the viewfinder), although the file names may be modified at a later time as discussed below.¹ For the monk seal, the standardized data form on which the image is recorded also includes a field for the image perspective and several seal-specific fields (ID, size, sex, and tag status).

File Naming Conventions and Uploading of Images

Digital cameras temporarily store images on transferable storage media ("Smart Media" cards or similar) that must be uploaded to a computer. While this task is relatively straightforward, it provides an opportunity to modify the default file name assigned by the camera to a more informative project-specific name. Simple batch files can be prepared to transfer the images from media cards to a working directory on the hard drive, while simultaneously renaming the files as desired. For the monk seal, the default four-character file name prefix assigned by the camera is replaced with a prefix that denotes the location and year (for example, *LA03* for Laysan Island 2003). These unique prefixes prove useful for distinguishing images taken at different sites and years after they are intermingled in the master database.

The Directory Structure

The purpose of the directory structure is to organize the images in a logical fashion to facilitate finding images of a particular seal by making searches for unidentified seals more efficient, and to serve as a backup in the event that the searching software fails and the user must resort to manual searches of the image library. In addition to those two principal purposes, the directory structure also helps to organize images collected for purposes other than identification.

The directory structure used for the monk seal organizes the digital images into branches that correspond to the most basic information likely to be collected for an unknown seal, such as *Male/Female* and *Tagged/Untagged*. When an observer encounters an unknown seal, these are the minimal attributes the observer is likely to collect from a distance. Within each of these branches, directories for individual seals known to occur in the subpopulation are created. Each of these seal-specific directories is named with the seal's permanent ID number. Within the branch for each sex, another branch is created for seals with uncertain IDs. This serves as a temporary repository for images of seals seen in the field and assigned temporary IDs until they can be matched with one of the known (permanent ID) seals.

The "Key Index" Hierarchy

A strategically designed directory structure, similar to the one described above, is

¹ If file names are changed in a subsequent step, there must be some means for "mapping" the new file names to those recorded on the field forms. This is generally possible by modifying only the camera-specific alphanumeric prefix assigned by the camera and retaining the assigned number.

analogous to the aforementioned monk seal scar card system, whereby users would look through multiple file boxes of hand-drawn scar cards in search of a card with features that closely match those seen in the field. However, such a directory-only system would be slow and inefficient and would fail to capitalize on the many advantages afforded by digital imagery. What is needed is the capability to specify particular features seen on an unknown seal and search within the image library for other images that represent the same trait.

Image recognition software to perform metrical analysis of morphological features (or automate the search process on those features) was considered for monk seal research, but we determined that in most instances identification of individuals depended on matching multiple, sometimes subtle, features that were not well suited to algorithmic interpretation. Therefore, we opted to manually assign certain criteria (primarily morphological traits) to each image that would later serve as search criteria. Computer-assisted searches could then be performed to match images with a set of search criteria. Many software applications are now available to manage digital libraries, including some very large commercial products that perform complicated tasks for enterprise applications. There are also a number of freeware and shareware products available, some nearly as feature-laden as the major commercial products.

We chose software that was easy to learn; was suitable for use by seasonal personnel with moderate computer literacy; was capable of organizing images, performing basic file management operations (renaming, moving, or copying files; creating directories; *etc.*), and displaying the images; could search the images according to certain criteria useful for seal identification (scars and other natural features); and was affordable. The software chosen for the monk seal project (SuperJPG, Midnight Blue Software, Inc., Virginia Beach, VA) is by no means the only software available to perform these functions, but it has the basic functionality that may be useful in marine mammal research.

In SuperJPG, the search criteria are called "key indexes," and they constitute the core of the monk seal digital imaging system. A key index can be defined as any characteristic useful for distinguishing among individual seals. The purpose of the keys is to quickly identify all of the images in the database that share a common attribute, such as *Mid-dorsal Shark Scar*, *Right-Foreflipper Natural Bleach*, or any other descriptive feature. By inspecting all of the images that have the specified criteria, the user can determine which image(s) best match the specific features seen on an unidentified seal.

In SuperJPG, the user first creates a list of key indexes and then assigns particular keys to each image using drag-and-drop operations or other commands. The key index data are then stored in a separate, usually proprietary format, data file within the image's directory. The image file itself is not altered by the key assignments. Any number of key indexes can be assigned to a single image.

Considerable thought went into planning the key index hierarchy to be used for the monk seal (partially visible in lower left pane of Fig. 1), and it was revised several times before being finalized. Conceptually, the key index hierarchy should encompass all of the characteristics that might be useful for distinguishing among

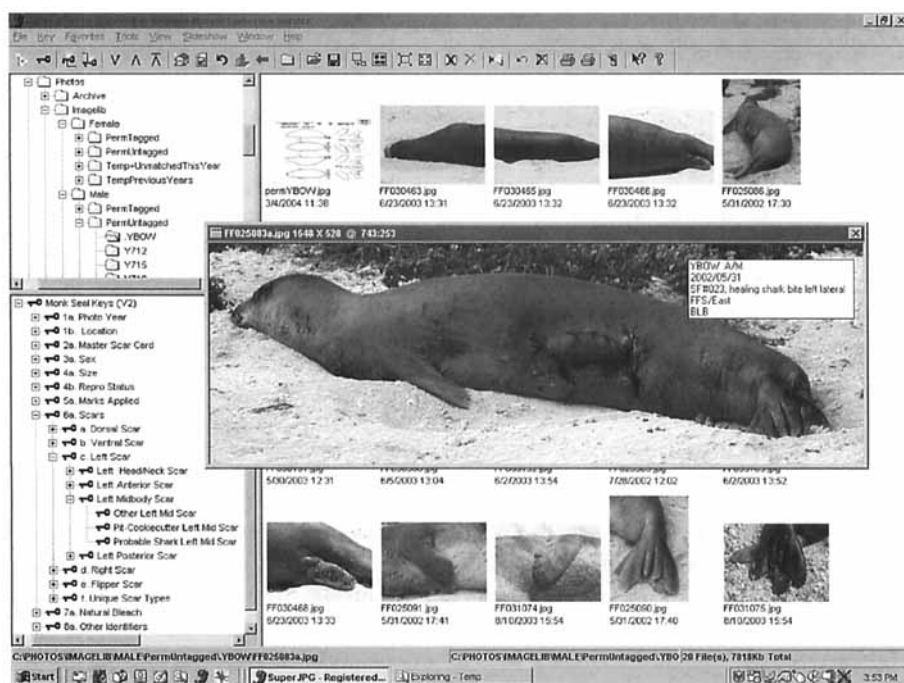


Figure 1. Screen capture of the main SuperJPG window, showing the directory structure (upper left), the searchable key index system (lower left), and the thumbnail pane (right side). One image opened for inspection is visible. This is one example of a “family” of software products that can be useful in managing digital databases.

individual seals and quickly homing in on a match for an unknown seal. Altogether there are over 200 different keys, organized hierarchically much like a directory structure.

One feature of the key index system that proves especially useful when performing searches is the “cascading” design of the system: assigning a key anywhere in the system implicitly assigns all of the parent keys (those within the same branch of the hierarchy but farther up the chain) to the image. Subsequent searches on either the specific key assigned or any of its parent keys, will successfully find an image. For example, assigning *Dorsal Mid-body Shark Scar* to an image and later searching on *Dorsal Mid-body Scar* will find that image. Thus, searches can be conducted at various levels of specificity to either broaden or refine the search results.

The set of key indexes includes some permanent features (e.g., *male/female* and *Dorsal Mid-body Shark Scar*), some quasi-permanent features (e.g., tag status), and some year-specific keys (reproductive status or juvenile size class that may vary annually as a seal grows). The year-specific keys are maintained for only the current and previous years and are purged thereafter. The key system for all field sites are exactly equivalent, so that the entire image library can be merged without compromising the functionality of the key index and search systems.

Double-clicking on an index key will display all of the images having that key

assignment in the right-hand (thumbnail) pane. The search can then be broadened or narrowed by single-clicking on another key, followed by one of three Boolean operators (*And*, *Or*, or *And Not*). The advantages of this system over the scar card system should be apparent. While a card can reside in only one physical place (*e.g.*, a file box containing cards for seals with one or several specific attributes, such as *Tagged Male*), a digital image can be instantly invoked through an index search on any number of attributes. This streamlines the identification process considerably by obviating the need to manually examine dozens (or hundreds) of cards to locate those that resemble the distinguishing traits of the unknown seal. Using the new system, the entire image library, which may consist of over 3,000 digital images at a breeding atoll (up to 290 seals, with 10–15 images per seal), can be searched in less than one minute through a single search sequence.

Additional Components and Maintenance of the Image Database

After the first year of full implementation, it became apparent that the size of the image library could quickly swell to nearly unmanageable size. The main source of the problem was images taken during a survey as an aid to help the researcher assign an ID to a known seal (one previously identified during the current season) already represented by multiple images in the image database. These “utility” images were often redundant to images already present in the seal’s directory and contributed little to the functionality of the system. To segregate these images from the main image library, we created a separate *Archive* branch, wherein redundant images were placed in separate folders for each seal. Additionally, field staff were advised to inspect the image sets for each seal if the number of included images exceeded 12–14 and determine if some images could be safely removed to the *Archives*.

Another key feature of the system is the concept of a *Master Scar Card*, which attends to one major weakness of the system that would otherwise limit its utility for seal identification. Each image can capture only one perspective of a seal (left, right, dorsal, ventral, *etc.*). However, in many cases, matching an unknown seal to a known seal requires the matching of features seen from several perspectives (*e.g.*, a scar seen on the left side, coupled with a natural bleach seen on the right side). No single image can capture both the left and the right perspectives; therefore, a search on the two features will result in zero image matches. The solution is to create a so-called *Master Scar Card* for each seal: a scanned image of a traditional scar card (either with or without a seal’s actual features drawn on it) to which all of the keys appropriate to the seal are assigned. Thus the *Master Scar Card* may have the keys *Female*, *Untagged*, *Left Mid-body Shark Scar*, *Right Anterior Natural Bleach*, *Ventral Posterior Pit-Cookiecutter Shark Scar*, *Right Hindflipper Partial Amputation*, and others. Performing a search on any combination of these keys will display a thumbnail of the *Master Scar Card* image, leading the user to inspect all of the images in the seal’s individual directory to see if they match the features seen in the field.

Once an unknown seal has been successfully matched, its identification number is entered into a separate Oracle database (Oracle Corp., Redwood Shores, CA), containing records of seal IDs, sighting histories, and other data across all sites and years. This database undergoes extensive cross-checking and validation before it is

used to generate a number of output files for demographic analyses and other purposes.

Much of the motivation for developing the digital image management system was to circumvent problems that plagued the traditional hand-drawn scar card system. The worst problem was the risk of misidentification of a seal from poor or inconsistent depictions that varied among observers. While that particular problem is reduced through the accuracy of digital images, a different set of problems can accompany reliance on digital photography.

The ease with which digital images can be acquired in the field presents an unexpected problem. In the haste to build an image library, individuals must exercise caution to avoid contaminating the database with images of uncertain identification. This is especially problematic in the early stages of the conversion to digital imagery when most of the seal IDs are established by comparison with older hand-drawn images or photographs, some of which may bear only a weak resemblance to what is seen in the digital photos. Once a questionable image has been cataloged as representing a particular seal (by placing it in the seal's directory or by other means), it will require special scrutiny to later recognize that the assignment is incorrect and remove it. It is far better to safeguard against these sorts of errors when the images are first cataloged. For monk seal images, the strategy is to isolate uncertain images in separate directories with temporary identification numbers until the ID of the seal represented in the images can be positively established. Another strategy would be to include some key indexes for Confidence Level in the tentative seal ID (for example, separate keys for *Positive ID*, *Likely ID*, and *Questionable ID*). Whatever system is used, it should be strictly adhered to so that the integrity of the image database is not compromised.

Volatility of the medium is another area where reliance on digital imagery is arguably less desirable than hard copy images. Hard drives sometimes crash, carrying with them a great deal of irreplaceable data. Strict protocols for regularly backing up the images and their associated system-specific files (files containing the key indexes or other ancillary data) are required.

Conversion to digital imagery for monk seal population assessment has many potential advantages over the traditional reliance on hand-drawn scars and photographs (Table 1). These include reducing interobserver variability, efficiency in searching for matches to establish seal IDs, elimination of the lag time and costs associated with film processing, and the ability to contain and transport the entire image library on several CD/DVDs (as opposed to multiple file boxes of scar cards and photo albums). Given the recent technological advances in digital imagery (including inexpensive, high-quality digital cameras and dedicated software for managing digital images), there are compelling reasons for embracing the new technology.

The applicability of our approach to other species depends on several factors. In general, this system, or some variant thereof, should prove useful in any study where individual identification depends on a suite of morphological characteristics not amenable to metric analysis. This is especially true if a sizable component of the population is unmarked, or if multiple observers, with varying degrees of artistic

Table 1. Comparison of traditional hand-drawn scar card to new digital image system for identification of individual Hawaiian monk seals.

Criteria	Scar cards and photos	Digital photos
Speed/efficiency?	Slow: 15 min to an hour or more to inspect candidate images	Fast: computer-assisted searches quickly find candidate images (less than 1 min)
Observer variability?	High	Negligible
Data immediately available?	Yes for scar cards; photos not available until months after field season	Yes, immediately accessible upon upload to notebook computers
Ability to search database from other sites?	Not possible until after field season	Yes (images from all sites provided on CD/DVDs)
Provisions for image backup?	None within-season; cards photocopied after season	Regular within-season backup to CD/DVD
Risk from loss or destruction?	Difficult to reconstruct database from photocopies and film negatives	Fairly simple: multiple backups available to restore database to hard drives
Physical size of medium?	Multiple scar card boxes and photo albums	Internal to notebook computers, with CD/DVD backups
Weight of medium?	High (up to 100 lbs for large populations)	Low (small number of CD/DVDs backups)
Relative cost?	High (cameras and film processing)	Low (digital cameras and CD/DVDs for backup)

aptitude, will participate in the project. In fact, given the quality of digital images and the efficiency of computer-assisted searches, it is hard to imagine a research context for which hand-drawn images would be superior to digital imagery in terms of cost, speed, or reliability.

There is a caveat to embracing digital imagery for wildlife research. We must continually remind ourselves that developing an image database is not an end in itself, but rather a useful tool toward achieving the broader objectives in population assessment and management of wildlife. While it is tempting to devote countless hours to refining the image management system, acquiring "perfect" images for every individual in the population, and so on, we should keep in mind that the system is "good enough" once it is acceptably efficient in guiding us to the images we seek for a particular task.

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