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Use of Digital Photography and Analysis of Dorsal Fins for Photo-Identification of Bottlenose Dolphins

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Abstract

The essential elements of a digital-based dorsal fin photo-identification program for dolphins are described and compared to more conventional film-based systems. The account begins with a description of digital-specific camera features, controls, and options, including sensor type, as well as image acquisition, resolution, compression, and storage. Detailed descriptions are given of how these digital-specific features are integrated with nondigital-specific features, such as autofocusing, shooting mode, metering, and telephoto lens specifications. The most compelling features of a digital-based system, especially when compared to film-based systems, are realized during the laboratory analysis of digital images (i.e., the processes of sorting, matching, and cataloging). During these laboratory phases of analysis, the most important system elements are the broad and powerful range of photographic image analysis, manipulation, and file management tools available in *Adobe Photoshop* Version 7.0 and the methods developed to integrate these tools into a system of dorsal fin analysis. This account concludes with a review of what the authors like most about the system and why, the process of transitioning from a film- to a digital-based system, and an analysis of the operational and acquisition costs of this digital dorsal fin photo-identification system.

Key Words: digital, photography, photo-identification, bottlenose dolphin, dorsal fin, *Photoshop*, film, *Tursiops truncatus*

Introduction

This paper describes the application of digital imaging technology to the acquisition and analysis of dorsal fin photographs of bottlenose dolphins (*Tursiops truncatus*). Our goal was to provide an integrated account of all aspects of digital dorsal fin photography targeted to an audience of individuals both experienced and new to the process of dorsal fin photo-identification.

We began our photo-identification studies of bottlenose dolphins within the Indian River Lagoon along Florida's central east coast in 1996, using a variety of 35-mm film-based cameras and telephoto lenses. Like many other film-based dorsal fin photo-identification programs (e.g., Defran & Weller, 1999; Defran et al., 1990), we found this approach satisfactory, but were intrigued by advances in digital imaging technology and the possibilities that this technology offered for all aspects of photo-identification methodology, including image acquisition, sorting, matching, and cataloging. We transitioned from a film-based to a digital-based methodology in 1998 and found that an entirely different approach to the analysis and archiving of dorsal fin photographs was required. In brief, the workbench for photographic analysis moved from the light table to the computer monitor; and analytic tools changed from the photographic loupe, slide projector, and paper tracings to the wide variety of photographic acquisition, analysis, and file management tools available in software programs such as *Adobe Photoshop* Version 7.0. Further, the process of archiving dorsal fin photographs moved from binders filled with slides to folders and files stored on a computer hard drive and backed-up on servers. At every level of the transition from a film- to digital-based system, the photo-identification process improved—in many cases, substantially.

During the last several years, we have been contacted for information about our digital methodology by a number of researchers contemplating the use of a digital-based dorsal fin photo-identification program. To make this information more useful, we adopted both an instructional, as well as a comparative (to film-based systems) and analytical approach. For some, this paper will involve coverage of familiar aspects of dorsal fin photography. In all cases, however, we sought to shorten the learning curve for those interested in this technology and its application. To accomplish this goal, we described the details of a "working system," which can be adopted as it is. We expect, however, that with continued hands-on experience, together with the rapid advances of digital photographic hardware and image-processing technology, most users will modify and expand this system.

Finally, in preparation for writing this paper, we reviewed available books, camera manuals, magazine articles, and websites specializing in digital photography. We also consulted with a number of colleagues familiar with digital photography and dorsal fin photo-identification. Many of these resources had useful information, but overall, this review strengthened our belief that a focused, detailed, and professional coverage of digital dorsal fin photography and analysis would be useful. Most books on digital photography were targeted to a point-and-shoot entry-level consumer audience, and we generally were disappointed in the depth and clarity of coverage available in manuals for even the most professional-level cameras, which were oriented to the operation of the camera's controls and coverage of its features. It is clear from the brochures that accompany many high-end camera systems that the primary consumers of professional-level cameras and related software are photojournalists and event photographers. In some cases, information related to these applications overlapped with the enterprise of dorsal fin photo-identification, while in others, quite different considerations prevailed.

The most comprehensive and informative book we found on digital photography was by Galbraith (1999). This book covers many technical aspects of digital photography and processing in a readable, useful, and well-illustrated way; however, its coverage is weighted towards early-generation professional-level digital cameras, accessories, software, and photojournalistic applications. Even so, it provides a particularly valuable tutorial for experienced photographers making the transition from film to digital platforms. For those who are relatively new to digital photography, Long (2001) provided a good entry-level introduction to the topic, written at a more thorough and detailed level than the point-and-shoot coverage mentioned above.

Digital Photography: Cameras, Lenses, and Photographic Techniques

In our experience, the demands of dorsal fin photography require many of the features and the sturdiness only available with top-tier professional cameras and lenses. Our experience with digital photography has been primarily with professional-level Canon cameras (EOS D2000, and EOS-1D) and lenses (EF 100-400 mm, f/4.5-5.6L IS USM), and these experiences are the foundation for much of the content of this section. Almost without exception, however, our research colleagues who are not using Canon cameras and lenses are using Nikon equipment. This division of brand fidelity between Canon and Nikon appears to mirror the preferences of other professional photographers using single lens reflex (SLR) cameras. Further, both Canon and Nikon offer many of the same features and use much of the same terminology. One exception is in the file compression formats Canon and Nikon use to store digital images on memory cards (discussed later). While terminology in this section is tied to our familiarity with Canon products, Nikon and other camera owners should be able to translate our descriptions with little or no difficulty.

Pixels, Resolution, and Shooting Speed

Digital cameras replace film with an image-sensing device, a memory storage card, and electronic circuitry, including the programmed instructions (called firmware) needed to integrate the functions of the sensory and memory elements. The image storage device consists of a two-dimensional array of millions of light sensitive elements, commonly referred to as pixels. Light entering the camera (the photographic image) is filtered to achieve color representation, and then color and brightness values are briefly recorded on the image storage device as an analog signal. Analog values from the image sensor are then quickly transformed into digital format and stored on a high-capacity memory device called a Compact Flash Card (discussed later). Two types of image-sensing devices currently are used in all digital cameras: (1) charge-coupled devices (CCD) and (2) complementary metal-oxide semiconductors (CMOS). Currently, CCDs are the sensors of choice because of their superior resolution, but they are more expensive to manufacture. Most experts agree, however, that the technical limitation of CMOS sensors (e.g., higher electronic noise levels and lower resolution) will soon be overcome and that they will replace or seriously compete with CCD sensors in digital cameras.

The resolution of dorsal fin photographs is largely determined by the number of pixels within the image sensor, along with the file format used to store digital images on the memory card. Currently, image sensors with a capacity of 3 to 11 million pixels (megapixels) are available on Canon and Nikon cameras. Some care should be used when interpreting the pixel characteristics found in the promotional literature used to advertise digital cameras. Often, the pixel capacity of the image sensor is given, although a more useful and lower pixel value is the number of recorded or "effective" pixels. On the EOS-1D, the total pixels of the image sensor is 4.48 million, while the number of effective pixels is 4.15 million, a reduction of about 7%.

While the potential resolution of a digital image increases with the number of effective pixels, so does the processing time required to convert the sensor image electronically to a stored file on the memory card. The most immediate liability of this increased processing time is a reduction of the number of frames-per-second (fps) the camera can take. For example, the Canon EOS-D60 camera, a high-end consumer model with an effective pixel count of 6.3 million, has a maximum continuous shooting speed of 3 fps; the EOS-1D, with 4.15 million effective pixels, has a maximum continuous shooting speed of 8 fps. The advantages of a higher fps capacity will be immediately obvious to those with some field experience photographing dolphin dorsal fins. In our experience, a high continuous shooting rate (5 to 8 fps) allows the photographer to better capture images of the surfacing and submerging sequence that exposes the dolphin's dorsal fin at the surface. A further advantage of the higher fps rate available with the EOS-1D is that it is linked to the predictive autofocus feature reviewed in the next section.

Light Sensitivity, Autofocus, and Metering

In both film and digital photography, the International Standards Organization (ISO) value (also termed ASA) represents the camera's sensitivity to light, with lower values (e.g., 100) representing lower sensitivity, and higher values (e.g., 400) representing higher sensitivity. The lower the ISO setting, the higher the apparent resolution. At higher ISO settings, the resulting image becomes grainier and image detail is degraded. In most cases, dorsal fin photography places a premium on the fine-grain resolution of details such as the nicks and notches found on the dorsal fin. Because the light available to form an acceptable image also is dependent on the aperture range (f-stop) of the lens and the shutter speed required to "freeze" the action of the moving dorsal fin, the minimum ISO setting is linked directly to these other variables. Except in very low-light conditions, such as early in the morning, late in the afternoon, and under very cloudy conditions, we found that a setting of ISO 200 works well. A convenient option available in digital photography is that the ISO setting can be changed from image to image under conditions of changing light levels in contrast to film photography, where the ISO setting must remain constant for any roll of film. As convenient as this option is, however, we rarely needed it, which is largely due to the dynamic range of aperture values available on the lens (EF 100-400 mm, f/4.5-5.6L IS USM).

Most high-end consumer, professional film, and digital cameras offer extensive control over the visual field sampled to focus automatically and determine the required exposure (metering) setting. For example, we chose between a wide (45), medium (11), or narrow (9) array, or a center point distributed within a centered ellipse in the viewfinder to determine the autofocus field (Figure 1 – Top). Similarly, we chose among a variety of metering options such as evaluative (all-around mode), partial (when the background is much brighter than the subject), center weighted (weighted at the center and averaged for the entire scene), or spot (weighted at the center covering 3.8% of the viewing area—see grayed area around the center point in Figure 1 – Bottom). We routinely used spot metering, which links this area to the autofocus point. We found this metering and autofocus combination to be a good accommodation for the fin portion of our photographs, which rarely fill the entire frame. Another advantage of spot metering is that it increases the autofocusing speed.

Two autofocus modes—One-Shot and AI (Artificial Intelligence) Servo—are available on Canon cameras. The One-Shot mode is ideal for still subjects, and the AI Servo is optimized for moving subjects such as in the dorsal fin application. We shoot exclusively in the AI Servo mode because it adjusts the focus point continuously while the shutter release is held in the halfway position, and it invokes a feature called predictive autofocus. Predictive autofocus tracks the

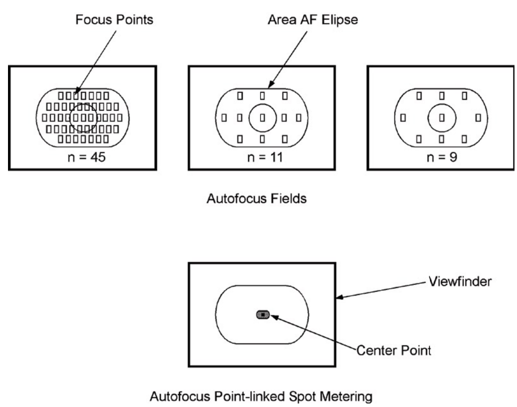

Figure 1. Schematic illustration of viewfinder autofocus and metering areas. Top: Optional autofocus fields of 45, 11, or 9 points. Bottom: Center point (3.8% of viewfinder) metering, which is autolinked to the focus point.

movement of the focal point subject, such as the dorsal fin, towards or away from the camera, and it automatically adjusts the focus point to compensate for this movement. This feature is useful when taking a single shot or when shooting in a continuous mode. As noted above, the focusing adjustments made by the predictive autofocus feature are linked to the continuous shooting speed range. Thus, the predictive autofocus feature enhances the likelihood that a high-speed shooting sequence will include one or more focused dorsal fin images.

Exposure Control and Drive Mode

Due to the fact that most dorsal fin photography involves the use of telephoto lenses, it is necessary to overcome lens movements that result from handholding the camera, tracking the dolphin as it surfaces and submerges, and boat movements. In combination, these movements can lead to blurred dorsal fin images. Almost all high-end film and digital cameras offer a variety of automated exposure control options, including automatic (P mode)—both the shutter speed and aperture values are selected by the camera; aperture priority (Av mode)—the photographer selects the aperture setting and the camera selects the shutter speed; and shutter speed priority (Tv mode)—the photographer sets the shutter speed and the camera selects the aperture setting. We found that it often is necessary to shoot in the Tv mode to overcome lens movements. When shooting with the EF 100-400 mm f/4.5-5.6L IS USM autofocus lens, we set the shutter speed between 1/800 to 1/1,000 s to accommodate for the longer focal length zoom settings we often used. Under bright light conditions, such as those in our Florida study area, we had good success shooting in the P mode. Our success in the P mode is due to the camera's firmware that detects the focal length setting of the lens and automatically increases the shutter speed for longer focal length settings. When shooting in the Tv mode, photographers using shorter telephoto lenses can select slower shutter speeds to mitigate movement.

While faster shutter speeds can eliminate lens and subject movement effects, they do so at the expense of reducing depth-of-field, which is the in-focus range on either side of the focus point. The greatest depth-of-field is achieved with the smallest aperture settings, which require slower shutter speeds to provide proper exposure. The advantage of wide depth-of-field values is that there is a greater likelihood that the target dorsal fin(s) will be in focus in spite of small errors in the focus point. So, the dorsal fin photographer must select the slowest shutter speed which reliably eliminates lens movement effects to achieve the greatest depth-of-field. As noted, depth-of-field increases with smaller aperture settings, and since the slowest acceptable shutter speeds are determined by the focal length of the lens (i.e., longer focal lengths require faster shutter speeds), it is important to choose the fastest (wide aperture) possible telephoto lenses.

Image Recording Quality

Dorsal fin photography requires the highest practical resolution that the camera and lens can achieve. Two interactive variables—image resolution and image compression—jointly determine the resolution of a dorsal fin image. The resolution setting determines the sampling strategy carried out by the image sensor. With the EOS-1D, high resolution images are sampled in the "large" setting and lower resolution images are sampled in the "small" setting. Once the image is sampled, it is quickly saved in one of two "lossy" compression (file format) modes: (1) fine—low compression JPEG (Joint Photographic Experts Group), or (2) normal—high compression JPEG. A third file format option called RAW saves images with "lossless" compression.

Much has been written about the advantages and disadvantages of lossy and lossless image compression algorithms, and a thorough coverage of the topic, while relevant, is beyond the scope of this paper. Briefly summarized, image compression (lossy) allows digital photographs to be saved in smaller files on the memory card; without compression (lossless), most dorsal fin photography would quickly fill the available space on a memory card. For example, the RAW format mentioned above uses a high resolution lossless format, but yields such large file sizes (~5 MB) that only a small number of images can be saved on even a high capacity memory card. Lossy compression algorithms, such as JPEG, are designed to exploit known limitations of the human eye, notably the fact that small color changes are perceived less accurately than small changes in brightness. Thus, JPEG is intended for compressing images viewed by humans as is the case with most dorsal fin photographs. On the negative side, lossy compression results in a decompressed image that is not quite the same (i.e., lower resolution) as the original. A useful property of JPEG, however, is that the degree of lossiness (i.e., lost resolution) can be varied by adjusting compression parameters. This means that the photographer can trade-off file size against output image quality. An alternative and lossless compression algorithm called TIFF (Tagged Image File Format) is available on some cameras such as the Canon EOS D2000 and the Nikon D1X; however, JPEG and RAW are the only file compression options available on the EOS-1D.

When using the EOS-1D, we shot all dorsal fin photographs using the large (high) resolution and fine (low) JPEG compression options with typical file sizes ranging from 1.7 to 2.0 MB.

Image Review and Tagging

Images may be reviewed and tagged in the field using the 5-cm^2 TFT LCD Monitor (160,000 pixels) on the back of the Canon EOS-1D and EOS 2000 cameras. Image review permits a quick determination that all required dorsal fin photographs have been acquired during a given sighting, thus reducing the amount of unneeded close contacts with dolphins.

During image review, individual images from a sighting may be selected or "tagged," and then untagged images (e.g., out focus, off-target, etc.) may be deleted, which preserves memory card space. Audio notes about a selected image can be recorded and attached to an image using a button-activated built-in microphone on the back of the camera. These "voice-tagged images" may note special conditions, confirm field identifications, mark shooting locations, and otherwise relay instructions and information from the photographer in the field to the analyst in the laboratory.

Memory Cards and Batteries

At the beginning of each survey, the date and time on the digital camera(s) is synchronized with the survey vessel's onboard GPS (Global Positioning System). Prior to the survey, all memory cards are cleared of previous images using the camera's "Delete All Images" function or by placing them within a memory card reader, which is a small, slotted device connected to the computer's USB port. The memory card reader functions as a dedicated peripheral drive, allowing card images to be copied and deleted.

Currently, we use memory cards with either 256 MB or 512 MB of storage capacity, and these cards can record approximately 100+ or 200+ dorsal fin images, respectively, in the high resolution JPEG format. Each memory card is labeled with a distinctive number that is used in pre-, during, and post-survey recordkeeping. Dorsal fin images are stored on the memory card in separate folders for each sighting. Folders are numbered sequentially on each survey day, as are image files within folders. The folder number and the range of image numbers within that folder, as well as the camera (EOS-1D or EOS D2000), lens, and memory card number, are recorded on the data sheet for each sighting.

Prior to each survey, all batteries are discharged and recharged (new batteries are discharged and charged four times to extend battery life). Battery life on both the EOS-1D and EOS D2000 cameras is usually sufficient to capture over 500 images, exceeding the number typically taken even on the most prolific surveys. Nonetheless, a backup battery is carried for each camera on all surveys. Battery life may be extended by minimizing the amount of image review, tagging, and deletion during a survey. Extra and high capacity memory cards hedge against the need to review and delete images to preserve memory card space.

Analyzing Digital Dorsal Fin Images: Sorting, Matching, and Cataloging

We adopted the following labeling conventions in this section: main menu selections of software under discussion are capitalized (e.g., File Browser); lower-level options within main menu selections are labeled with single quotation marks around the option name and capitalized (e.g., 'Sort by Rank'); single quotation marks are used to mark letters, letter combinations, or words when used as labels (e.g., . . . the letter 'B' is assigned . . .); and double quotation marks are used around terms and capitalized for emphasis (e.g., The "Best" photographs . . .).

Folders and Images from a Sighting

Memory card folders and files are downloaded to the network server when we return to the laboratory or to a laptop hard drive (and later to the server) when in the field for several days. At this point, folders are renamed according to the survey date and sighting number. Whenever possible, we avoid deleting images from a memory card until the nightly backup of the server is complete, and a log is kept of each labeled memory card download.

Sorting

The goal of sorting is to identify and place the best dorsal fin image of each dolphin into a final folder for that sighting. In the laboratory, the process of sorting begins by opening and reviewing folders containing images from a sighting using the File Browser utility in *Adobe Photoshop* Version 7.0. The File Browser lets the laboratory technicians view, sort, and process image files, as well as create new folders and rename, move, rotate, and delete images. Additionally, individual image file information and data imported from the digital camera (e.g., file size, resolution, camera settings, etc.) are displayed. The 'View' is set to 'Large with Rank' and sorted by 'File Name' and 'Ascending Order' (Figure 2). Under these settings, images from the folder are displayed as a matrix of pictures in the order taken. The serial image number assigned by the camera (e.g., F36B0001, F36B0002, etc.) and an unassigned 'Rank' (e.g., Rank: -) is displayed below each image (Figure 2). These images are serially and repeatedly reviewed to identify (1) well-focused dorsal fin photographs suitable for further analysis and (2) images which are not of sufficient quality (e.g., out of focus, off target, etc.) for further analysis.

During this preliminary stage of analysis, single or multiple images may be selected within the File Browser and opened, tiled, and displayed on the monitor as larger images used for closer inspection. Single or multiple tiled images may be manipulated with the Hand and Magnifying tools, which allow the dorsal fin to be centered and enlarged within each displayed image.

After low-quality images are deleted, the remaining images are renamed using the 'Batch Rename' option within the File Browser. The 'Batch Rename' option is accessed by first making sure that no images are selected in the File Browser 'View,' and then right-clicking the mouse cursor in the space surrounding the displayed images. All images in the folder are renamed using the sighting date (Yr, Mo, Day), sighting number, and a three-digit serial (sequential) number (Figure 3).

After renaming the image file, the 'Ascending Order' preference is deselected to reverse the order of the images. Thus, when multiple, sequential images are opened from the 'View,' they appear on the screen in the order they were shot. The analysis begins with the last image (i.e., the first image shot) of the 'View.'

When analyzing a sighting, the objective is to determine how many dolphins have been photographically captured. This objective is achieved by assigning a different letter (or 'Rank') to each individual in the sighting. Beginning with the first image shot, the letter 'A' is assigned as the 'Rank' for that dolphin. If the second image is of the same dolphin, it is also assigned the letter 'A' as its 'Rank.' If the second image is of a different dolphin, then the letter 'B' is assigned as its 'Rank,' and so forth. Continuing this process, letters are assigned to all images in the sighting. On survey days when over 26 identifiable dolphins are photographed, the letters 'A-Z,' 'AA-ZZ,' and then 'AB-AZ' are assigned. Since these preliminary letters are arbitrary and are assigned each day, they begin again with 'A' on the next survey date.

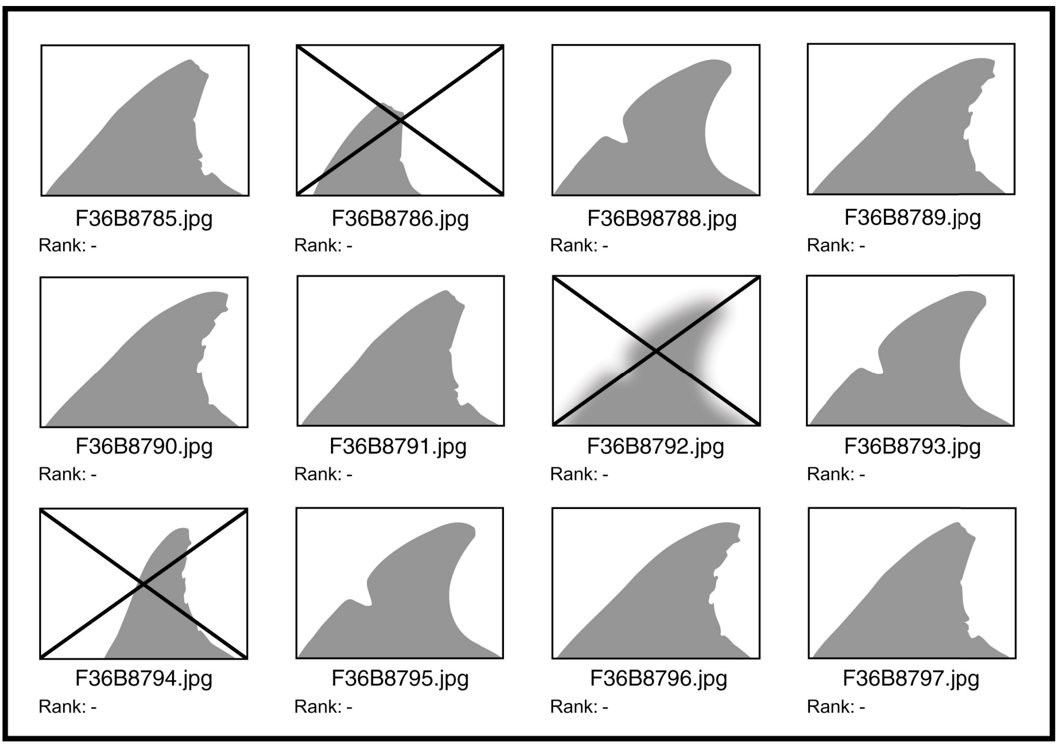

Figure 2. Images opened from a sighting folder with *Adobe Photoshop*'s File Browser; images are sorted by 'File' name and displayed using the 'Large with Rank' options within the File Browser. Sorting by file name preserves the original sequence in which the images were photographed. Images judged to be of inadequate quality for further analysis are deleted (marked with an X above).

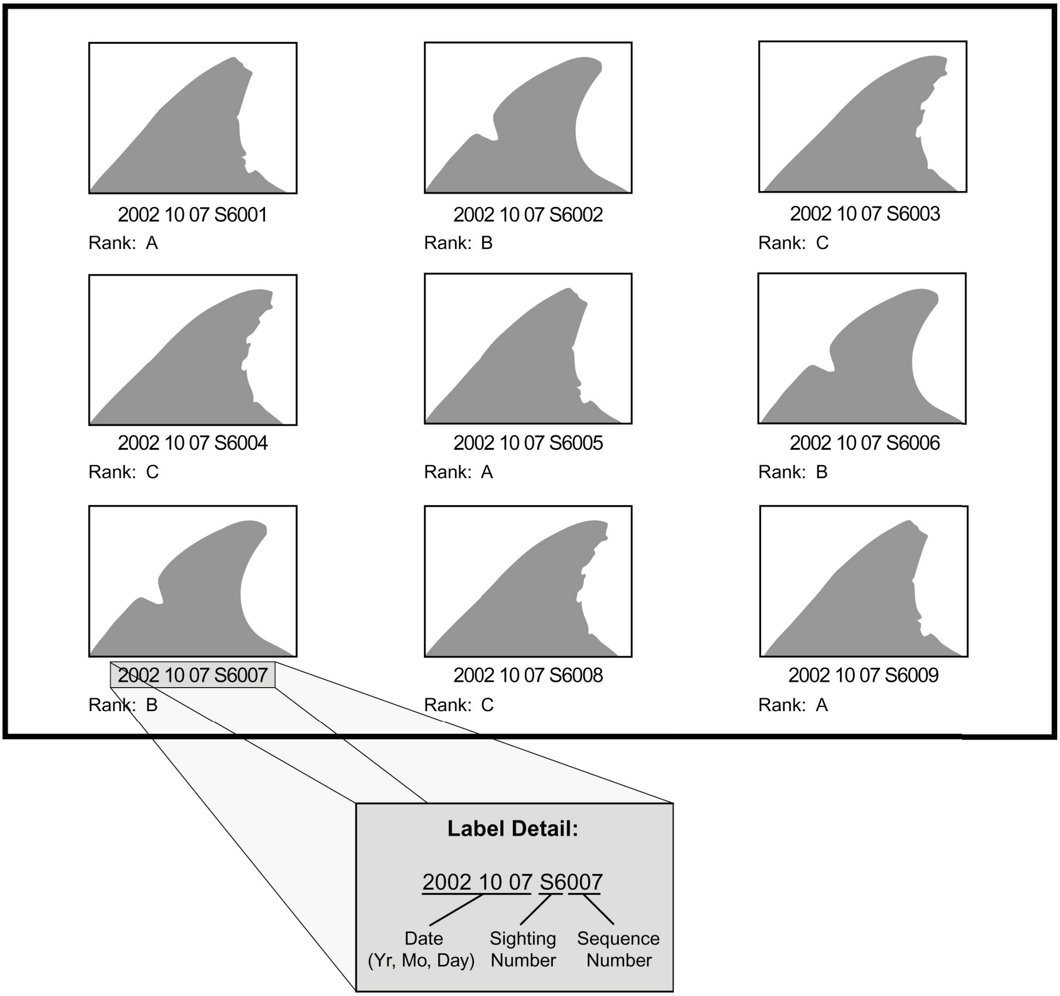

Figure 3. Renamed images (see "Label Detail") from the sighting folder; during initial analysis, images judged to be of the same dolphin are given the same temporary identification label (letter) called the 'rank.'

After all images have been assigned a letter 'Rank,' they are sorted by 'Rank' in the 'View' to group all of the images of each dolphin. All images of dolphin 'A' are opened, and redundant (near identical) or poorer quality images of this dolphin are deleted. After the best image of each dolphin has been selected, the label "Best" is added after the letter 'Rank.' These "Best" photographs of each dolphin are used when searching for matches in the Master Catalog (discussed below).

Judgments about whether dorsal fin images are of the same dolphin and the degree to which these dorsal fins are judged to be distinct are made using a variety of criteria. Some of the photographed dolphins have a sufficiently distinctive pattern of notches on the trailing and leading edge of their dorsal fin that can be matched to good quality dorsal fin photographs from other sightings. Other individuals may only have a combination of small dorsal fin nicks, notches, scars, and blemishes that (1) can be matched to other photographs of the same individual within that sighting, (2) can distinguish them from other individuals within that sighting, or (3) cannot be matched to individuals from a different sighting. These distinctions are potentially confusing to the new analyst because they attempt to differentiate between individual dolphins judged to be "distinct" within and across sightings and those judged to be distinct only within a sighting. In our experience, virtually all dorsal fins within a sighting for which a high-quality photograph has been obtained are sufficiently distinctive to permit at least 'within sighting' identifications. An important application of knowing the number of 'within' and 'across sightings' distinct dolphins in a completely photographed sighting (see Photograde One type sightings in Urian & Wells, 1996) is that it allows a determination of the proportion of 'across sightings' distinct dolphins in the population. This proportion is a critical component in the calculation of population abundance estimates (Wells et al., 1996).

Image processing and review during this 'sorting' phase requires diligent analysis and can be tedious and time consuming, especially when the number of images or the sighting size is high. The display enhancement and labeling tools available in *Photoshop* are substantial, however. In the early portion of the analyst's learning curve, the Zoom and Hand tools will be the ones most often used. As his or her skill level with *Photoshop*'s many image manipulation features increases, control over image brightness, contrast, and orientation; overlaying images for comparison; and keyboard shortcuts will become increasingly valuable additions to his or her digital image analysis skills.

Matching

The goal of the matching process is to determine whether dolphins from a sighting are in the existing catalog or are new additions to the catalog. The "Best" photograph (type specimen) of all previously identified and distinctly marked dolphins is kept in the Master Catalog of dorsal fins. This catalog contains folders organized by the location of the most distinctive fin notch or feature, which are labeled as follows: Leading Edge, Missing Top, Tip Nick, Upper Third, Middle Third, Lower Third, and Entire (Urian & Wells, 1996).

Comparisons between the best quality dorsal fin images from a sighting with those in the Master Catalog are carried out using *Photoshop* and *Picture Viewer* (a component of the *Windows XP* operating system). With *Photoshop* and *Picture Viewer* both open, right clicking on an open space in the *Windows XP* task bar, and then selecting the 'Tile Windows Vertically' option will cause the windows from both programs to be displayed simultaneously side-by-side (Figure 4). An alternative enhancement we recently adopted is the use of multiple monitors that display one program per screen (i.e., *Photoshop*, *Picture Viewer*, and *Microsoft Access*). Under this arrangement, sighting images are opened one at a time in *Photoshop*, while images from folders in the Master Catalog are opened in *Picture Viewer*. *Picture Viewer* then is used to scroll, one image at a time, through the Master Catalog category folders, beginning with the folder that best matches the most distinctive feature of the fin in the sighting image. If a match is not made when the images in the most likely folder have been searched, then the images in all other folders of the Master Catalog are examined for a possible match. During this process, potential matches in the Match Catalog can be opened and examined in *Photoshop* to take advantage of its extensive array of image manipulation tools (e.g., Zoom, Brightness and Contrast, Rotation, Transparency, and Layering, etc.).

If a match is made between the new image and an image in the Master Catalog, it is evaluated for consideration as the "Best Photograph" of that individual. If the sighting image is a better photograph than the one in the Master Catalog, then it replaces the original. If no match is made between the sighting image and the Master Catalog, then this photograph is added to the Master Catalog as a new "type specimen."

Cataloging

The goal of cataloging is to assign final names to dolphin image files from a sighting, to store these image files within appropriate folders, and to record photographic sighting information in our Access Database. Dolphin names are assigned using the conventions described in Urian & Wells (1996). Each dolphin in this labeling system is assigned a four-letter code, such as BENT, TOSC, and ZIPP, that refers to their longer name such as BENT fin, TOp SCoops, and ZIPPer. When possible, names such as these are selected to refer to some representative and easily remembered feature of that dolphin's dorsal fin. Once a dolphin is identified in the Master Catalog or is determined to be an addition to the Master Catalog, its four-letter code is added to the image's file name. Image file names from a sighting are modified in *Photoshop*'s File Browser by using the 'View' sorted by 'Rank' option. Then, the appropriate code is added to the last part of the label for each dolphin having the same preliminary letter. When it is not possible to assign a code, as is the case with fins that are judged to have only within-sighting distinctiveness, UNK (Unknown) is assigned to designate their unknown identity. In these cases, the UNK label is followed by the letter 'Rank' for each fin (e.g., UNK/A, UNK/B, UNK/C, etc.).

After all image file names have been modified to contain their code, they are stored in the folder for that sighting. In addition, the best image of each distinctive ('across sightings') dolphin from that sighting is stored in a separate Sighting History Folder maintained for each dolphin. All distinctively marked dolphins ('across' as well as 'within sightings') are recorded in the Access Database record for that sighting.

To facilitate field identification of dolphins, the Master Catalog is downloaded to a laptop or PDA (Personal Desk Assistant). Alternatively, Master Catalog images can be printed and taken into the field. When printed, these Master Catalog images are cropped to a 5 cm x 5 cm size, with the dolphin's name and sighting information added to the lower right corner of the image using the *Photoshop* Type tool. The cropped image is then placed into an image template (prepared in *Adobe Photoshop*) designed to hold 20 images. This template is printed at 300 dpi, and the images are cut out and placed into clear slide storage pages (Clear File ArchivalPLUS™ Slide Pages), ordered by category, and alphabetically arranged by name.

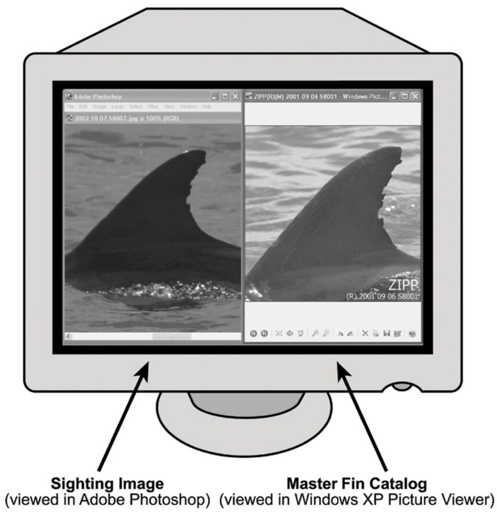

Figure 4. The best image of each dorsal fin from a sighting is displayed in a *Photoshop* window (left). Comparison images from the Master Catalog are displayed in an adjacent window (right) using the *Windows XP Picture Viewer*. Potential matches from the Master Catalog are then evaluated by scrolling, one image at a time, through the most likely, and then all, dorsal fin category folders.

System Evaluation: A User's View

This section represents a collective synthesis of the authors' opinions and impressions, vis-à-vis a systematic empirical assessment, about the merits of the digital dorsal fin photo-identification system we described above. In almost all cases, the authors used their substantial experience with film-based dorsal fin photo-identification systems as a reference point for the evaluations. We describe what we like the most about this system and why.

Image Quality

It is tempting to think that we take much better dorsal fin photographs with digital cameras than with film-based cameras. We suspect, however, that if this is true, it has more to do with the construction quality and sophisticated features available on contemporary film and digital SLR cameras and lenses, and with our progress along the dorsal fin photographer's learning curve. In fact, based on an analysis of resolution alone, our digital images are not as good as those produced under the same circumstances by a film-based version of the EOS-1D (i.e., the EOS-1V) (see Markowitz et al., 2003, for a digital to film photo-identification comparison). While film to digital resolution comparisons are both controversial and difficult to make (see Lyons, 2002, for a good review), the consensus is that images from a Canon EOS-D60 (6.3 effective megapixels) have about 72% of the resolution of professional grade 35-mm slide film. While factors other than resolution also contribute to the quality of a photographic image, we conclude that most SLR digital images are not better photographs than film-based photographs. This situation appears ready to change, however, with Canon's recent introduction of the EOS-1Ds (11.1 effective megapixels, which rivals professional grade slide film in its resolution, as well as the development of Foverons' X3 chip (Levin, 2002). The slower fps capacities of these high-resolution cameras and chips, however, remains a serious obstacle.

Image Analysis

Resolution and "Best Photograph" comparisons notwithstanding, it is the extraordinary access to the details of images, as well as the opportunity to manipulate these images, that we find so compelling about digital-based photo-identification. Rather than viewing 35-mm format film on a light table with an 8x loupe, we view our digital photographs as greatly enlarged images on 47.5-cm monitors. The convenience of working with digital images in this way is even more dramatic when making visual comparisons among images. Rather than switching back and forth between small 35-mm images enlarged with a loupe, which requires that we hold fin details in our visual memory, we are able to vertically tile and view two or more large images on the monitor simultaneously (Figure 4). With *Photoshop* we are able to quickly and greatly enlarge fin details of specific interest in a particular image, and then easily return to a tiled display of large comparison images with a few mouse clicks or keystrokes.

We conclude that digital dorsal fin analysis is best when things are most difficult (i.e., during the sorting phase of image analysis). During this process, the film analyst is confronted with numerous tedious tasks, including developing (or having developed) numerous rolls of film, isolating film strips and images in separate envelopes by date and sighting number, and reviewing film strips from a sighting while maintaining the sequence integrity (exposure number) of individual images. The time, effort, and visual drain on the film analyst are multiplied when there are a large number of photographs taken during a sighting (e.g., many dolphins, many photographs, or both). In contrast, we found that all aspects of the sorting phase, including the initial organization, evaluation, and 'within-sighting' matching of individuals, are eased considerably when working with digital images (Figures 2, 3 & 4).

During the matching phase, some film-based photo-identification laboratories attempt to accommodate for the difficulty of making comparisons between small 35-mm images by printing photographic enlargements (Urian & Wells, 1996) or by tracing enlarged projections of dorsal fin images, as we did during our early work (Defran et al., 1990). Such accommodations have considerable limits such as the loss of photographic detail when attempting to make initial matches based on tracings. We found that the side-by-side visual comparisons available on a digital system (Figure 4), along with the opportunity to easily and quickly zoom in for greater detail and out again for comparing multiple images, greatly expedites and increases the accuracy of the matching process.

We found that earlier cataloging of film-based dorsal fin images, including archiving, storing, and accessing, was a bulky and laborious enterprise. Worse, there was no economical technology available for making back-up copies of photographs. Digital dorsal fin images, like other computer files, however, are cost-effective and convenient to store, access, copy, print, back up, and move between workstations and servers. Also, duplicates of the same digital images can be stored easily in folders for the same individual and for each sighting. Finally, entire digital-based photo-identification catalogs can be shared with other stakeholders such as management agencies and other scientists seeking to make regional comparisons.

Final Comments

Transitioning from Film to Digital Photography

Established photo-identification programs that transition from a film- to digital-based format have a labor intensive, but worthwhile process to complete. We converted our film-based images to a digital format using a dedicated film scanner. Currently, the highest resolution available in an affordable film scanner (~ 700 to 1,200 USD) is 4,000 dpi, which captures almost all available information from a slide or negative. The advertised time required to scan a single image at the highest resolution is under 60 sec, although we found these estimates somewhat optimistic. In our laboratory, a batch scanning attachment that allows up to 50 individual slides to be scanned in a session has become a useful accessory. Currently, some 4,000 dpi film scanners come with a low-capacity batch option, or they make a high-capacity batch processor available as an extra cost option.

A somewhat different labeling system is used for scanned film image files (cf. Figure 3, "Label Detail"), with the roll and frame number replacing the digital sequence number (e.g., 1998 07 25 R2F10S1 [yr, mo, date, roll number, frame number, sighting number]). Rather than scan every image in our film archives, only the best photograph of each distinctively marked dolphin from a sighting was scanned. These scanned files, like their digitally photographed counterparts, were saved in a folder of that dolphin's sighting history (see "Cataloging" section above).

How Much Does It Cost?

Two common questions about the digital-based photo-identification system we have described are (1) "How much does it cost?" and (2) "Is it less expensive than a film-based system?" The short version of our reply is a less satisfying "It depends" to the first question, and a more satisfying "Yes" to the second question. Photo-identification programs already using Canon and Nikon compatible autofocusing lenses will find that their major expenditure is for a digital camera body. The best prices for the EOS-1D and EOS D60 were at about 5,000 USD and 2,000 USD, respectively, several months ago, but have dropped by about 10% and 20%, respectively, since then. High-capacity memory cards and back-up batteries represent additional expenditures that we regard as "must have" additions to a digital system. The second most important element of a digital photo-identification system is a computer workstation equipped with a processor speed of at least 700 kHz, but preferably ≥ 1 mHz, 250 MB to 512 MB of RAM (Random Access Memory), a high-capacity hard drive (≥ 60 GB), a read/write compact disk drive, and a 42.5- to 47.5-cm CRT monitor. For most photo-identification programs, such workstations are an existing fixture and do not represent an additional expenditure. For many workstations, therefore, the only needed upgrade may be to the capacity of their hard drive and for the purchase of a high-capacity back-up hard drive or comparable space on a remote server. Finally, we regard *Adobe Photoshop* Version 7.0, a somewhat expensive program, as an indispensable workstation tool for carrying out digital photo-identification analyses.

We considered the question of cost comparisons between film- and digital-based photo-identifications systems from both an operating and acquisition perspective. The first comparison was easy because the cost of buying, processing, and sometimes printing film-based media is high, while processing digital images is practically free. The cost of acquiring new professional or high-tier consumer film and digital cameras is about the same. For existing film-based programs, the cost of new digital camera bodies will be significant. For programs that take many images, the cross-over point where savings from film not purchased overcomes the cost of new camera bodies will come quickly. For more modestly image-productive programs, the crossover point will be reached more slowly.

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