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Methods of Photo-Identification for Small Cetaceans

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ABSTRACT

Photo-identification of naturally marked cetaceans helps obtain information on group structure, site fidelity, movement patterns and population size. In conjunction with other studies, long-term photo-identification can also enhance descriptions of life history parameters such as age at sexual maturity, calving intervals and reproductive and total life span. Photo-identification can be carried out from shore and boats, with additional information available from airplanes for certain species. Thirty-five millimetre single lens reflex cameras with motor drive, data back and fixed or zoom lenses from 50 to about 300mm are used most often. Film types and storage and retrieval systems vary widely with investigator preference. The technique of photo-identification is powerful and not usually disturbing to wild animals; its refinement and increasing sophistication (such as use with high-resolution video) promise to make it increasingly important in life history and social system studies of small cetaceans.

INTRODUCTION

Historical overview

Early researchers of animal behavior and ecology recognized that aspects of their studies were enhanced by the recognition of individuals. Von Frisch (1962; 1974) marked honey bees (*Apis mellifera*) to study communication about foraging locales; Lorenz (1937) learned to recognize particular greylag geese (*Anser anser*) by natural markings and behavior, as he determined aspects of imprinting. Although artificial marking and tagging was considered almost a prerequisite for behavioral work in the 1950s and 1960s, increasing numbers of long-term studies of wild animals have shown that (especially large and long-lived) vertebrates can usually be identified from natural marks (with the possible exception of most birds, which have, for this purpose at least, the unfortunate tendency to perpetually change their feathers). Zebras, *Equus* sp. (Klingel, 1965; Peterson, 1972), black rhinoceroses, *Diceros bicornis* (Goddard, 1966; Mukinya, 1973), giraffes, *Giraffa camelopardalis* (Foster, 1966), African elephants, *Loxodonta africana* (Douglas-Hamilton, 1973), lions, *Panthera leo* (Schaller, 1972), chimpanzees, *Pan troglodytes* (Goodall, 1986) and bonnethead sharks, *Sphyrna tiburo* (Myrberg and Gruber, 1974), provide examples from the vast literature of studies relying at least in part on knowing who is who in the population. A recent bibliographic compilation of papers which discuss marking and tagging of aquatic animals (Emery and Wydoski, 1987) presents 166 references on 'biological marks' of invertebrates, fish, amphibians, reptiles, birds and mammals – with most emphasis on fish. Individual identification has indeed become a staple of field research, and in the last 15 years or so especially, researchers of cetaceans have begun to take advantage of natural marks. Identification of pinnipeds still relies mostly on tags (e.g. see Peterson and Bartholomew, 1967; Gentry, 1975), but there too the balance may be shifting towards the use of natural markings (e.g. see Hiby and Lovell, 1990).

The casual identification of individual cetaceans has been around for a long time, probably about as long as humans have interacted with coastal species. One example is that of killer whales (*Orcinus orca*) in Twofold Bay, Australia, in the nineteenth and early twentieth centuries, where whalers and fishermen identified some of at least 27 individuals, apparently mainly by markings on and near the dorsal fin (Wellings, 1944; Mitchell and Baker, 1980). More recently, anomalously white harbor porpoises, *Phocoena phocoena* (McIntosh, 1912; Kleinenberg, 1936), Pacific white-sided dolphins, *Lagenorhynchus obliquidens* (Brown and Norris, 1956; N. Black, Moss Landing Marine Labs, pers. comm.) and bottlenose dolphins, *Tursiops truncatus* (Essapian, 1962; Caldwell and Golley, 1965) have been occasionally seen. Data on 13 species of anomalously white cetaceans were summarized by Hain and Leatherwood (1982). Likewise, Caldwell (1955) had several sightings of a distinctive bottlenose dolphin with a damaged fin, and thus made inferences about the home range of this animal.

The concerted use of often subtle natural marks to study herds or groups of animals in a particular area, however, began over a short period in the early 1970s, with the advent of long-term field studies of live cetaceans. Individuals of killer whales (Balcomb, Boran and Heimlich, 1982; Bigg, 1982), Indo-Pacific humpbacked dolphins, *Sousa chinensis* (Saayman and Tayler, 1973; 1979), bottlenose dolphins (Shane, 1977; 1980; Würsig and Würsig, 1977) and Hawaiian spinner dolphins, *Stenella longirostris* (Norris and Dohl, 1980) were all recognized and cataloged in order to provide information on occurrence and intra-group affiliation patterns (Fig. 1). As far as we can tell, the extensive use of natural marks began for four odontocete species in five widely separated projects all within about a two– to three-year period (without information exchange between the researchers involved) and provides a good example of an idea 'coming of age' due to scientific inertia in the field. At the same time, recognition of humpback whales, *Megaptera novaeangliae* (Katona, Baxter, Brazier, Kraus, Perkins and Whitehead, 1979) and Southern Hemisphere right whales, *Eubalaena australis* (Payne, 1972; 1976; Payne, Brazier, Dorsey, Perkins, Rowntree and Titus, 1983) became an exciting new tool in the study of baleen whales. Today it is recognized that with good enough photographs, a reasonable portion of the population of almost any cetacean species can be individually identified (Table 1 provides a partial list of small cetacean studies which have

2 Nick	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LF	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
RN 2	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Fuzzy	●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●
F's calf	●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●
CF	●	●	●	●	●	○	○	○	○	○	○	○	●	●	●	●	●	●
B	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○
OWS	●	●	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○
WR	●	●	●	○	○	●	●	●	●	●	●	●	○	○	○	○	○	○
TS	●	○	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○
Moon	●	○	●	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○
NIP 2	●	○	●	○	○	●	●	●	●	●	●	●	○	○	○	○	○	○
A	●	●	●	○	○	●	●	○	○	○	○	○	○	○	○	○	○	○
DN	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
New A	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
N-N	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
NC	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
New RN	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
SQ Not	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	●	○	○
New Fuzz	○	○	○	●	●	●	●	●	●	○	○	○	○	○	○	○	○	○
CFC 2	○	○	○	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○
SM Flag	●	●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	○	○
SM Nick	○	●	○	●	○	○	●	○	○	○	○	○	○	○	○	○	○	○
Conc	●	●	○	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○
A SM Fin	○	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
AS	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
SLN	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
New Nick	○	○	○	○	○	●	●	●	●	○	○	○	○	○	○	○	○	○
H	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○
HI RN	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
2 Dent	○	○	○	○	○	○	○	○	●	●	●	●	●	○	○	○	○	○
BF	○	○	○	●	●	●	●	○	●	○	●	●	●	○	○	○	○	○
TRN	●	●	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●
Flag 2	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
SM Nip	○	●	●	●	○	○	●	●	●	●	●	○	○	○	○	○	○	○
CFC 1	○	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
LSN	○	●	●	●	○	○	●	●	●	●	●	○	○	○	○	○	○	○
Low Nick	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
RN	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
Nip	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Hi Fuzz	○	●	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Fuzz 3	○	○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	○	○
SM LO Not	○	○	○	○	○	○	●	○	○	○	○	○	●	○	○	○	○	○
Rev Not	○	○	○	○	○	○	○	○	●	○	○	○	●	○	○	○	○	○
X	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
SM WR	○	○	○	○	○	○	○	○	○	○	○	●	●	○	○	○	○	○
LDN	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●
Top Nick	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
VLN	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
CFC 3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●
ASM 2	○	○	○	○	○	●	●	○	●	●	●	○	○	○	○	○	○	○
ASM 3	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●
CFC 4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
Month	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Year	1974 |			1975												| 1976		

Fig. 1. Summary of occurrence pattern of 53 photo-identified bottlenose dolphins during an 18-month period. Solid circles indicate presence of animals at least once during that month (after Würsig, 1979).

utilized natural marks). Confirmation of the validity of photo-identification by natural markings has come from studies which combine this technique with various sorts of tagging (Irvine *et al.*, 1982; Scott *et al.*, 1990).

Importance of individual identification

The recognition of individual animals can be used as a tool for a rather large variety of natural history information. Perhaps the most common use for dolphins has been in ascertaining group composition and 'fidelity' of certain animals to the group (examples include, for bottlenose dolphins, Würsig, 1978; Shane, 1980; dos Santos and Lacerda, 1987; Wells, Scott and Irvine, 1987, and for spinner dolphins, Norris, Würsig, Wells, Würsig, Brownlee, Johnson and Solow, 1985). Area distribution, short-term movement patterns and migrations can be ascertained when photographs of animals are obtained at more than one locality (Norris *et al.*, 1985; Wells, Hansen, Baldridge, Dohl, Kelly and Defran, 1990). Recognizable animals allow for the basic descriptions of surfacing-respiration-dive cycles, and their correlation to general behavior patterns such as resting, socializing, travelling and feeding (Tayler and Saayman, 1972; Würsig, 1978). Recognizable dolphins also allow for a more thorough description of inter-individual behaviors, especially if sex and reproductive conditions are known (Conner and Smolker, 1985; Wells, 1986; Wells *et al.*, 1987). Mark-recapture techniques may be applied to obtain an estimate of population size (Hansen, 1983, 1990, for bottlenose dolphins; Hammond, 1986, for general review for large whales, but which is also applicable to dolphin studies). In order for such estimates to be realistic, natural marks should be recognizable over time, be unique to the individual and have an approximately equal probability of being sighted and resighted. The latter is probably the most difficult criterion to establish, since some individuals are much better marked than others, and since some animals are also more camera (boat) shy than others. Those individuals whose markings are not distinctive enough to be certainly recognized in future good quality photographs should not be used in an analysis of population size (Hammond, 1986), but may be used for movement and range information.

Life history information can be greatly enhanced when individuals, preferably recognized from early life, are followed for many years (Bigg, 1982). Age at sexual maturity, calving intervals, length of nursing, reproductive and total life span, and occasionally information on disease and mortality rates, can all be ascertained in longitudinal behavioral studies without the need for sacrificing animals. The longest such dolphin study using natural markings, tagging and radio-tracking, which now also incorporates information on genetic relationships between animals, and thereby gets close to identifying the social-sexual system of the population, is by Wells and co-workers in the Sarasota-Bradenton area of west Florida (Irvine and Wells, 1972; Wells, Irvine and Scott, 1980; Wells, 1986; Wells *et al.*, 1987; Wells and Scott, 1990).

Photogrammetry, which involves measuring the size and spacing of animals by either stereophotography or photographing objects at a known distance, has been used extensively in recent years (e.g. Cullen, Shaw and Baldwin, 1965 for fish; Major and Dill, 1978 for birds; Klimley and Brown, 1983 for sharks; Davis, Koski and Miller, 1983 and Cubbage and Calambokidis, 1984 for bowhead whales, *Balaena mysticetus*; Gordon, 1986 for

Table 1

Studies of small cetaceans in which individuals have been identified by natural markings.

Species	Major distinctive features	Area	Source
Belukha whale, *Delphinapterus leucas*	Scars on body	Hudson Bay, Canada	Caron & Smith, 1985
Killer whale, *Orcinus orca*	Dorsal fin shape and nicks, scars on back and shape of light saddle patch	Vancouver Isl., Canada USA	Bigg, 1982; Balcomb *et al.*, 1982; Balcomb and Bigg, 1986; Bigg *et al.*, 1987
		Southern Alaska, USA	Leatherwood *et al.*, 1984; Hall and Cornell, 1986; Ellis, 1987
		Patagonia, Argentina	Lopez & Lopez, 1985
		Iceland	Lyrholm *et al.*, 1987
		Norway	Lyrholm, 1984
Short-finned pilot whale, *Globicephala macrorhynchus*	Nicks, scratches, scars and pigment patterns on dorsal fin and back	Catalina Isl., Calif., USA	Shane, 1984, 1986; Patten & Samaris, 1985
		Japan	Miyashita *et al.*, 1990
Indo-Pacific humpbacked dolphin, *Sousa chinensis*	Scars on flank, back and dorsal fin	Plettenberg Bay, South Africa	Saayman & Tayler, 1973, 1979
		Moreton Bay, Australia	Corkeron, 1990
Atlantic white-sided dolphin, *Lagenorhynchus acutus*	Scars and nicks on dorsal fin, and unusual pigment patterns	Gulf of Maine, USA	Belt & Weinrich, 1985; Belt, 1987
Dusky dolphin, *Lagenorhynchus obscurus*	Scars and nicks on dorsal fin, and unusual pigment patterns	Kaikoura, New Zealand	Cipriano, 1985; Würsig, unpubl. data
		Golfo San José, Argentina	Würsig, unpubl. data
Pacific white-sided dolphin, *Lagenorhynchus obliquidens*	Scars and nicks on dorsal fin; anomalously white individuals	Monterey Bay, Calif., USA	N. Black, pers. comm.
Bottlenose dolphin, *Tursiops truncatus*	Nicks, scars, scratches and pigment spots on dorsal fin	Golfo San José, Argentina	Würsig & Würsig, 1977; Würsig, 1978
		Western Florida, USA	Wells *et al.*, 1980, 1987; Wells, 1986; Irvine *et al.*, 1981
		Sanibel Isl., Florida, USA	Shane, 1987
		Aransas Pass, Texas, USA	Shane, 1977, 1980
		Galveston, Texas, USA	Jones, 1988
		Matagorda Bay, Texas, USA	Gruber, 1981
		Mobile Pt., Alabama, USA	Goodwin, 1985; Heimlich-Boran & Heimlich-Boran, 1987
		Southern Calif., USA and west coast of Baja Calif., Mexico	Hansen, 1983, 1990; Kelly, 1983; Defran, Kelly *et al.*, 1990 Defran, Schultz and Weller, 1990
		Central Calif., USA	Wells *et al.*, 1990
		Gulf of Calif., Mexico	Ballance, 1987
		Shark Bay, Australia	Connor & Smolker, 1985
		Moreton Bay, Australia	Corkeron *et al.*, 1987a,b; Corkeron, 1990
		Sado Estuary, Portugal	dos Santos & Lacerda, 1987
Risso's dolphin, *Grampus griseus*	Pigment patterns, nicks on dorsal fin, and scars on back	Monterey Bay, Calif., USA	Kruse, 1988
		Azorean Isl.	Arnbom *et al.*, 1988
Spinner dolphin, *Stenella longirostris*	Scars and marks on dorsal fin	Kona coast of Hawaii, USA	Norris & Dohl, 1980; Norris *et al.*, 1985
Atlantic spotted dolphin, *Stenella frontalis*	Fin and fluke marks and body spot patterns	Bahamas	Byrnes *et al.*, 1989
Heaviside's dolphin, *Cephalorhynchus heavisidii*	Anomalously white animals, and dorsal fin nicks	Western South Africa	Rice & Saayman, 1984
Hector's dolphin, *Cephalorhynchus hectori*	Dorsal fin nicks	New Zealand	Slooten & Dawson, 1988; Dawson & Slooten, 1987
Harbor porpoise, *Phocoena phocoena*	Dorsal fin scars and nicks, and pigment areas	Bay of Fundy, New Brunswick, Canada	Watson, 1976; Watson & Gaskin, 1983; Gaskin & Watson, 1985
Dall's porpoise, *Phocoenoides dalli*	Dorsal fin pigmentation, color pattern anomalies, and dorsal fin deformities	Monterey Bay, Calif., USA	Loeb, 1972; Jefferson, unpubl. data
		Puget Sound, Wash., USA	Miller, 1990
Baiji, *Lipotes vexillifer*	Facial coloration patterns	Yangtze River, China	Würsig & Tershy, 1989; Yuanyu *et al.*, 1990.

sperm whales, *Physeter macrocephalus*; Whitehead and Payne, 1981 for right whales; Gordon, Papastavrou and Alling, 1986 for blue whales, *Balaenoptera musculus*; Heyland, 1974 for white whales, *Delphinapterus leucas*; and Scott, Perryman and Clark, 1985 for pelagic dolphins, *Stenella* spp.). Although it does not require the identification of individuals, measuring the size of known animals can greatly help in ascertaining differential age-sex use of particular areas (Davis *et al.*, 1983) and in establishing growth rates and other life history information over time. A potentially powerful technique is the use of underwater photogrammetry to describe positioning of individuals in dolphin schools in similar vein to work by Klimley (1981) and Klimley and Brown (1983) on scalloped hammerhead sharks (*Sphyrna lewini*).

METHODS FOR SMALL CETACEANS

Distinctive features

For most dolphins and porpoises, the trailing edge of the dorsal fin, which tapers from front to back to a thin sheet of flesh and connective tissue, is the most identifying feature. The area abrades and tatters easily, especially in some species. Populations of bottlenose dolphins, for example, often have greater than 50% of individuals identifiable (Würsig and Würsig, 1977; R.S. Wells, Brookfield Zoological Society, Brookfield, Illinois, pers. comm.), while Hawaiian spinner dolphins (Norris and Dohl, 1980; Norris *et al.*, 1985), dusky dolphins, *Lagenorhynchus obscurus* (Würsig, unpubl. data), pilot whales, *Globicephala macrorhynchus* (Shane, 1984), Dall's porpoises, *Phocoenoides dalli* (Jefferson, unpubl. data) and Pacific white-sided dolphins (N. Black, Moss Landing Marine Laboratories, pers. comm.) typically have only about 20% or less identifiable individuals. Other features which may help to identify individuals include: shape of the dorsal fin; shading of the fin and upper body; scrapes, scratches and wound marks; and pigment patterns. A well-marked individual is one that is recognized not by a single feature, but by a matrix of marks which, in human-related terms, form a distinctive 'face' for the individual. When we rely on one or two simple dorsal fin notches, we may often accidentally lump two or more dolphins as the same individual, and thereby obtain grossly incorrect information on numbers, residency, etc. The senior author is well aware of this potential pitfall, for he has at times made this mistake, until clear and sharp close-up photographs showed detailed markings which allowed for separation of similar-looking animals.

Longevity and changeability of marks is of critical importance to those factors, such as population estimates from mark-recapture studies, which require long-term recognition. There are no hard and fast rules on how long marks last, however. Dorsal fin tatters probably last for life, except that addition of marks near or over a previous mark can obscure identifiability. Bigg, Ellis, Ford and Balcomb (1987) have recognized some killer whales for over 15 years and it is likely that the same can be done for most small delphinids. Wells *et al.* (1987) have recognized several bottlenose dolphins for about 18 years, and Würsig and Harris (1990) have found that some bottlenose dolphin dorsal fins changed not at all over a 12-year period. It is not known, however, whether other individuals changed beyond recognition during that time. Recently, the rate of wound healing has been addressed, especially for bottlenose dolphins (Bruce-Allen and Geraci, 1985; Lockyer and Morris, 1985; 1990; Corkeron, Morris and Bryden, 1987a). Dolphins heal even large open wounds within a matter of months, but wound scars seem to last for very long times, probably for life. Cookie cutter shark (*Isistius brasiliensis*) bite scars may be found all over the bodies of mature spotted dolphins (*Stenella attenuata*, Würsig, pers. obs.) and spinner dolphins (Jones, 1971; Norris and Dohl, 1980), and it is well known that Risso's dolphins (*Grampus griseus*) accumulate scars throughout life (McCann, 1974 discusses body scarring in sperm whales, delphinids, beaked whales and river dolphins).

Studies from shore

Dolphins which habitually come close to shore may be observed from land, especially where high cliffs or hills provide a good perspective. Land observations and photography do not 'bother' the animals, and that is a great advantage. They are also relatively inexpensive, within the reach of anyone with a camera and telephoto lens. Examples of species which have been studied from shore are bottlenose, dusky, Indo-Pacific humpbacked and Hawaiian spinner dolphins; as well as harbor, Burmeister's and Dall's porpoises (Würsig and Würsig, 1979; 1980; Saayman and Tayler, 1979; Norris *et al.*, 1985; Taylor and Dawson, 1984; Würsig, Würsig and Mermoz, 1977; Jefferson, 1987). However, high vantage points, which are optimal for behavioral observations (and for theodolite tracking, Würsig, Cipriano and Würsig, 1990) are usually not optimal for individual recognition. Only occasionally can aberrant pigment patches on the dorsum of some dolphins be used from high vantage points, and we have found that for most efficient use of dorsal fin patterns and upper body shadings, photographs should not be taken from more than 15m above sea level, nor from further than about 500m from the dolphins (approximately the maximum range with good resolution for a 1000mm lens on a heavy professional tripod). High vantage points are, of course, fine for the large cetaceans such as blue, gray (*Eschrichtius robustus*), bowhead, and right whales, which are identified largely by body markings. Killer whales, with their large dorsal fins and often striking marks, have also been identified from cliffs (Kruse, 1990).

A common procedure is to take photographs of dolphins from the beach with a 300mm lens, preferably but not necessarily on a tripod. A general rule of thumb is to take hand-held photographs at shutter speeds no less than the inverse of the lens size (e.g. using a 300mm lens requires a minimum shutter speed of 1/500s). No lens larger than a 500mm mirror lens should be hand-held. Focus is of critical importance, and it is desirable that a lens is stopped down by at least one f-stop for adequate depth of field. Because dolphins may have different markings on each side of their bodies, ideally one should obtain photographs from each side. This is not always possible because the group may be moving alongshore and may not present their other side. Photographs so obtained should rely mainly on dorsal fin marks which are visible from both sides, although other photos are of course still of value if they can be used for subsequent reidentification of a dolphin from the same side, or can later be linked to a dolphin with both-side photos. Bigg, Ellis and Balcomb (1986) used the convention of making the left side 'most important' for identification of killer whales, but ideally both sides should be photographed if possible. Bottlenose dolphins often behave perfectly for shore photography, since groups patrol certain nearshore areas by going back and forth and presenting both sides to the patient investigator who may wait for several hours for the group to return. A potential problem with gaining group compositional data over times when the group is out of sight of the investigator is that groups may split up or converge, and composition may change (at times, in rather subtle fashion) during the course of the photo session. In areas where it is possible, an investigator may move along shore with a moving group, and thereby obtain a more thorough documentation of identifiable animals.

Motor-drive 35mm cameras are optimal for field photography, but manual wind cameras are adequate if the investigator learns to rapidly and smoothly advance photo frames as dolphins surface. At certain times when a group of dolphins is relatively small (less than 20) and compact (covering less than about 30m diameter), motor-drive cameras allow for photography of all individuals which surface, and thereby one can obtain data on dive times of known individuals (by linking frames shot to tape-recorded notes in real time), and on affiliations by proximity of surfacings. This rapid-fire photography makes use of the 35mm format to essentially recapture a ciné effect of motion, and the senior author has found the technique of value for shore-based photography of bottlenose dolphins (Würsig, 1978). Non-commercial 8 or 16mm ciné usually does not provide the resolution or high shutter speed required to adequately capture small identifying marks, although recently developed high-resolution video has been found to show most marks of bottlenose dolphins and bowhead whales (pers. obs.)

Studies from airplanes

While shore-based studies are the least invasive and least expensive, airplanes at low altitudes tend to affect the behavior of marine mammals to a larger degree and are expensive. But airplane-based studies are sometimes called for in remote areas and some distance from shore. For example, Payne (1972; 1987) has photographed southern right whales from the air for over 18 years (see also Bannister, 1990; Best and Underhill, 1990), and bowhead whales have more recently been identified from the air as well (Braham and Rugh, 1983; Rugh, 1990). Dolphins, however are usually not individually identifiable from the air, although patterns of associations, and (in clear waters) actual numbers of individuals in a school can be estimated more accurately (Scott *et al.*, 1985). With calibrated equipment and known altitude above water, individual lengths and inter-individual spacings can also be measured (M.D. Scott, Inter-American Tropical Tuna Commission, La Jolla, CA, pers. comm.). Aerial photography should not be attempted with a lens greater than 300mm or at a shutter speed less than 1/250 sec. To prevent distortion, photos should be taken through an open window or through photo-optical glass of a window or a flat-paned airplane belly port, and the lens should not point into the airstream. Unless careful attention is paid to these details, photos taken from the air will usually be disappointing.

A reasonable altitude for behavioral descriptions and photographs which does not affect the behavior of dolphins and whales seems to be about 152m (500ft) for circling single-engine airplanes, and 304m (1000ft) to 457m (1500ft) for larger twin-engine variable pitch propeller planes. This is not a rigid rule, however, for amount of disturbance is greatly affected by depth of water (often more disturbed in shallow water), species, width of circle around the animals and general behavior. For example, when socializing or feeding, dolphins are often less easily disturbed than when resting or travelling.

Studies from boats

Observations and photographs from boats represent the most practical approach to studying groups of dolphins for the vast majority of species and in most areas. From boats one can find dolphins, move with them and manoeuvre near the group for the best possible view. However, boats are potentially disruptive to the natural behavior of dolphins. Boat operators must learn to approach dolphins slowly, with unvarying motor speed, not to drive through the school, but parallel to the school, and not to turn in front of it; in general, to use common sense so as to minimize herding the school with the vessel. For observational and photographic work, we much prefer a small (<10m), manoeuvrable vessel. This allows a close approach, often to within 5–10m of individuals, and allows for low-angle photography. Fast speeds which prompt most dolphin species to ride the bow and stern waves are to be avoided, as this disrupts normal behavior, and the spray thrown up by dolphins generally obscures the dorsal fin and back. Photos should be taken as perpendicular to the body axis as possible; and for dolphins, the fin and back must generally appear large enough in the frame so that a 1cm nick is visible.

We prefer a variable focal length (zoom) lens for photography from boats, with an approximately 80 to 200mm lens being preferable for most dolphin species. This allows us to rapidly change settings for dolphins which are close to the vessel and for dolphins 20m or more from the vessel. Because of close proximity to most dolphins of a group while manoeuvring near them, it is possible to be selective (when the objectives of the study allow it), i.e. to take photographs of only dorsal fins and backs which appear to have markings. The selective technique saves film (nevertheless, the senior author has been known to take 500 photos of a single group of 10 to 15 animals) and limits identification to less subtle marks which are more likely to result in unambiguous resightings in the future. However, this selective technique may at times miss identifiable dolphins.

There exists a statistical technique to ascertain whether or not every identifiable member of a group was in fact photographed and therefore acknowledged as present. It consists of taking at random, as many photos as possible of members of the group within constraints of time and budget. An *a posteriori* count of at least four identifiable photos per recognizable dolphin indicates that no dolphin was missed in the photo record (with a probability level of 95%). In other words, if 10 recognizable dolphins are identified during a photo session, and at least four photos exist of each, it is likely that there were only 10 identifiable dolphins present (Würsig, 1978; Ballance, 1987; Fig. 2). The technique is powerful, for it can say with high confidence that a particular animal not seen on a particular day was in fact not present. For small dolphin groups, in which each individual may be identifiable, the technique can also give actual group sizes instead of the traditional estimates. The technique is, of course, not limited to boat-based work, but because it requires quite a few photographs taken of dolphins at random, it generally necessitates well over 30 minutes of contact time with dolphins, obtainable by motoring with them.

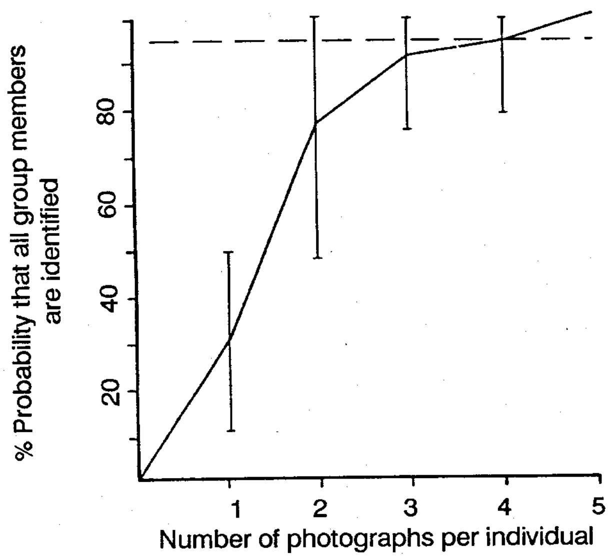

Fig. 2. Percentage probability that all group members are identified plotted against the number of photographs per individual (see text).

Other techniques

Since photography is done from a distance and since many dolphins are sexually monomorphic, it is often not possible to assign sex to particular recognizable animals. It is possible to take advantage of, at times brief, glimpses of the genital area when dolphins roll ventrum up at the surface and when they breach with belly towards the camera. With some experience, it is possible to take the photo of the ventrum and then take a second photo of a recognizable fin or back of the same animal as it presents its usual side to our view. Appropriate annotation of the photo sequences is of critical importance here.

Probably the best manner of rapidly annotating sections of film in the field is to take a picture of a non-dolphin subject subsequent to the important sequence, and note the event into a comment cassette tape recorder or into a field notebook. This is termed 'blanking' the film, and 'blanks' should consist of objects (a cloud, the boat's engine, a colleague, another boat), not a featureless true blank, since a series of such featureless blanks confuses analysis of the film. Blanks can indicate particular sections of groups, size or sex relationships, sequences of film, and any other desired detail. One may think of the 'blank' as being as important as the identification photos.

Underwater photography is another aid to identifying and sexing individuals, but is limited to relatively clear waters. Underwater photographs can be obtained by free diving and by photographing from a vessel with underwater viewing ports (for example, Evans and Bastian, 1969; Norris and Dohl, 1980; Norris *et al.*, 1985). No study has relied heavily on photo-recognition of animals underwater, simply because more clear photos can be obtained above water with less effort. Nevertheless, the linking of photos to sex and inter-animal affiliations, as well as the use of photogrammetry for size and spacing information, mentioned earlier, makes underwater photography a potentially valuable tool for future work (e.g. see Glockner-Ferrari and Ferrari, 1990, working with humpback whales; Byrnes, Black and Leatherwood, 1989, working with Atlantic spotted dolphins, *Stenella frontalis*).

EQUIPMENT, SUPPLIES, AND ANALYSIS

General

We have already mentioned, in general terms, that 35mm cameras with motor-drive capability are appropriate tools. Data backs which electronically print date and time (and sometimes other notes) onto each frame, are also desirable. Many modern cameras have built in 'auto-focus' capability. Some of these auto-focus cameras are remarkably fast and accurate, and reliably focus on even small dorsal fins which subtend only a portion of the 35mm frame. They allow relative amateurs to obtain sharp photographs without the extensive period of self-training normally required to aim, focus and shoot in the about 1 sec. of a dolphin surfacing.

Telephoto lenses used for shore-based photography are generally around 300mm in size although lenses of up to 1000mm have been used (Würsig and Würsig, 1977 used a 1000mm non-mirror lens, f 5.6, for much of their photo-identification of bottlenose dolphins). We have noted that lenses of more than 300mm should not usually be used from airplanes. A wide variety of lenses have been successfully used from boats: from wide angle (we use 24mm) for photographs of bow-riding dolphins, to variable length (zoom) lenses about 80–200mm for most work, up to a maximum of 300mm lenses. The lenses should be as fast as possible without undue weight; an f 4.5 300mm lens is quite appropriate. However a more expensive f 2.8 300mm lens, is probably too heavy for most researchers to comfortably hand hold for extended periods of time, and the gain in lens speed may not be worth the loss in stability.

We suggest the mounting of cameras and long lenses onto commercially available or home-made gun stocks or shoulder braces, which allow for stabilizing the unit with the body, for boat work. The firing mechanism of the camera should be extended to a trigger at the regular position of a gunstock; the hand not at the trigger is used for focussing and f-ring adjustment. Use of such a stabilizing mount depends of course on personal preference, and some researchers believe that the mount adds too much bulk and weight to be worth the effort.

Film types and development procedures

Most large-whale researchers tend to prefer fast films, and commonly shoot ISO 400 *Kodak* Tri-X black and white film at ISO 1600. This necessitates development with special high-speed chemical mixtures such as commercially obtainable *Acufine* or *Edwal FG-7* (Bigg *et al.*, 1986; Hall, Rainer, Reed and Roberts, 1987). *Ilford* XP1 and *Ilford* HP5 taken at ISO 1600 are also favorite films (Bigg *et al.*, 1986). The fast film speed allows for fast shutter speeds (1/1000 sec., for example) to freeze action (and camera movement), and simultaneously provides for a large depth of field, since f-stop settings can often be adjusted to the lens's midrange, or f 8 to 11. High-speed color film, such as *Kodachrome* 200 or *Ektachrome* 400, is less often used.

We find that for dolphin and porpoise photography, a film near or under the speed of ISO 100 is usually adequate for most light conditions. Since marks are often small and subtle, and dorsal fins and backs subtend only a small fraction of most 35mm frames, small grain size and maximal resolution of film emulsion are often necessary, and the faster speed films are sometimes too grainy. We also find that color slide film brings out often subtle differences in body hues and shadings, and our personal choice is *Kodachrome* ISO 64. If color slide film is too expensive for continual use, we recommend any good black and white film around ISO 100, such as *Kodak Plus-X* (ISO 125) or the new *Kodak T-Max* 100 (ISO 100). *Plus*-X can be developed in *Kodak* Microdol solution, thinned one part to three parts water, for fine grain resolution. Color slide film should always be kept handy, however, for those animals with fresh wounds or other color marks. Film may be bought in bulk 16.5 or 33m rolls (one 33m roll fills 18 36-exposure cassettes) and home-rolled to reduce price. We emphasize that our choice of film speeds and types represents a personal bias obtained from experience with often poorly identifiable dolphins. Other researchers prefer to work with faster film speeds even for dolphins, and the choice ends up being one determined largely by personal preference related to particular species.

Storage and analysis

Analysis techniques vary widely among researchers. Many examine black-and-white negatives or diapositive color slides directly through 8-power optical lupes or through variable power dissection microscopes. Others look at proof sheets made from negatives and print promising frames onto 12.5 x 18cm (5 x 7") sheets of photographic paper. We use a combination of methods with black-and-white negative film, examining film through a dissection scope and printing appropriate frames. Slides may also be looked at with a dissecting microscope, but we prefer projection onto a wall, using a slide projector with a zoom lens. This allows us to rapidly trace dorsal fins and backs onto standard sheets of writing paper, and with the variable-power lens, change the size of the image to properly fill the paper. 'Type specimens' of animals are created in this manner, and other photographs are compared to these.

Several workers have developed methods of speeding up manual methods of storing, classifying and matching photographs. Where many different groups work with the same animals (as in killer whale studies in Washington and British Columbia) or where over 1,000 identifications exist (as in humpback whale studies in the North Pacific and Atlantic), computer-assisted retrieval and matching is of great help (e.g. see Hiby and Lovell, 1990; Mizroch, Beard and Lynde, 1990; Whitehead, 1990). Our own dolphin dorsal fins are not computerized mainly because only one or a few people of the same project are dealing with only several hundred identifications.

Whether or not photos are stored by electronic means, the researchers must make decisions on what criteria to use to categorize the many photographs. In humpback whales, a major criterion is the amount and patterning of white on the lower side of the flukes (Katona *et al.*, 1979). For dolphins, we have traditionally used the number and types of dorsal fin notches for filing and retrieval. All single, double and triple notches are filed together; and round, square, or triangular notches are cross-referenced. We have also measured the relative placement of notches top to bottom of the dorsal fin for cross-referencing. Scratches or other fin and body marks are filed separately.

We especially like the technique for analyzing and cataloging dorsal fin photographs developed for bottlenose dolphins by Defran, Shultz and Weller (1990). While these investigators trace negatives or slides onto paper and file them by number of fin notches, as we do, they also create a 'Dorsal Ratio', which consists of measuring the distance between the two largest notches and dividing that by the distance of the lower measured notch to the top of the fin (Fig. 3). The resultant ratio is unaffected by non-perpendicular placement of the fin in the photograph, and it does not take into account the bottom of the dorsal fin, a location that is difficult to judge in most dolphin species due to the tapering of the fin towards the body. By convention, the top of each notch is used as the measuring point.

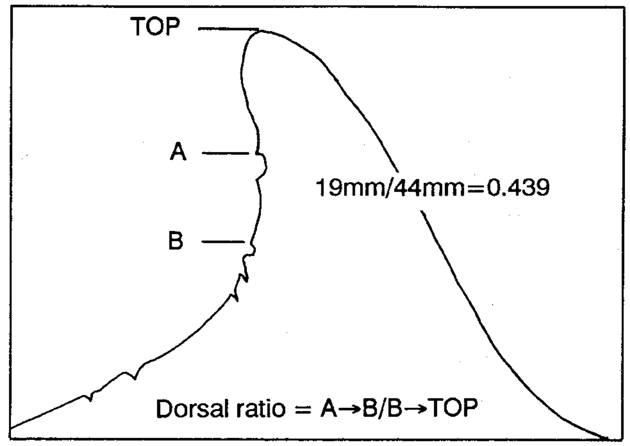

Fig. 3. Dorsal fin tracing and calculation of the dorsal ratio (after Defran *et al.*, 1990).

CONCLUSIONS

We have seen that the requirements for useful identification photographs of the smaller cetaceans are basically the same as those of the baleen and large toothed whales. Dolphins surface much more briefly than whales, however, and the investigator must learn to focus and take pictures very rapidly. Because fin notches and other marks are often relatively small compared to large whale marks, finer-grain films are generally desired (unfortunately, requiring slower speeds).

Photographic identification of cetaceans is a powerful and relatively benign technique which, at least for dolphins, has not yet reached full potential. We wish to see more population estimate studies relying in part on mark-recapture information from photographs. We also believe that at least in some populations, such as with Hawaiian spinner dolphins and bottlenose dolphins in many areas, it is possible to better link identified dolphins to sex and relative age. Photogrammetry will be useful here, and the application of high resolution video, which takes individual frames at up to 1/4000 sec., and thereby eliminates blurring of frames, will allow for frame-by-frame analysis of all dolphins of a group. Video does not presently have the resolving capability of 35mm photography, however, and for subtle notches and marks, cannot yet replace standard still photography. Photo-identification will continue to be facilitated by refinement of existing techniques and by advances in technology. By itself, however, photo-identification will not reach its full potential in providing information on cetaceans. Instead, its use with other data-gathering techniques, such as focal animal studies, capturing animals for blood hormone and chromosome analyses, etc., will allow us to learn ever more about the lives of small cetaceans.

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