

A review of the effects of different marking and tagging techniques on marine mammals

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Abstract. Wildlife research often requires marking and tagging animals to collect data on survival, reproduction, movement, behaviour and physiology. Identification of individual marine mammals can be carried out using tags, brands, paint, dye, photogrammetry, telemetry and other techniques. An analysis of peer-reviewed articles published from January 1980 to April 2011 addressing the effects of marking revealed a preponderance of studies focussed on short-term effects such as injuries and behavioural changes. Some marking techniques were reported to cause pain and to change swimming and haul-out behaviour, maternal attendance, and duration of foraging trips. However, marking has typically not been found to affect survival. No published research has addressed other possible long-term effects of marking related to injuries or pain responses. Studies of the more immediate effects of marking (mostly related to externally attached devices such as radio-transmitters) have shown a variety of different types and magnitudes of responses. It is important to note that studies failing to find treatment differences are less likely to be published, meaning that the present and any other reviews based on published literature may be a biased sample of all research conducted on the topic. Publishing results that found no or low impacts (i.e. best practices) as well as those that found significant impacts on animals should *both* be encouraged. Future research under more controlled conditions is required to document acute effects of marking, including injury and pain, and to better understand longer-term effects on health, reproduction and survival. We recommend that studies using marked animals standardise their reports, with added detail on methodology, monitoring and sampling design, and address practices used to minimise the impact of marking on marine mammals.

Additional keywords: marine mammals, marking effects, survival, telemetry, transmitter.

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Introduction

Wildlife research often requires marking or tagging animals to obtain individual data on behaviour, survival, reproduction, home range use and resource selection (Merrick *et al.* 1996; Murray and Fuller 2000). Methods for long-term identification include brands, implanted coded tags, scarring (e.g. toe or fin clipping) and external numbered tags attached to ears, legs or flippers (Merrick *et al.* 1994; Horning *et al.* 1999; Murray and Fuller 2000; Wells 2002; Lander *et al.* 2005). Methods used for short-term identification include paint, hair dye and electronic instruments glued to fur and feathers, or carried around necks and legs (e.g. VHF radio-tags or satellite-tracking tags). Some marking and tagging techniques have been used for centuries (e.g. branding), and others have been used for less than a decade (e.g. internally implanted satellite tags).

Data from marked animals are important for applied research, but the marking or tagging techniques may come at a cost to the animal. Some changes in behaviour or physiology due to marking

may be sufficiently severe as to affect the ability to interpret data from marked animals. Effects of marking can also extend from the individual animal to populations and interactions between species.

Studies on a range of bird and mammalian species have shown that markings can cause pain and distress, interfere with natural behaviour, and reduce survival and reproduction (Pavone and Boonstra 1985; Pietz *et al.* 1993; Schwartzkopf-Genswein *et al.* 1997c; Swenson *et al.* 1999). For example, zebra finches (*Poephila guttata*) fitted with coloured plastic leg bands showed mating preferences for particular colours (red, pink and black bands) while avoiding mating with other birds fitted with light-blue or light-green bands (Burley *et al.* 1982). The commonly used marking method of toe-clipping decreased the overall life span of meadow voles (*Microtus pennsylvanicus*; Pavone and Boonstra 1985). Animals carrying transmitters may also have higher mortality rates, as shown for moose calves (*Alces alces*; Swenson *et al.* 1999) and meadow voles

(Webster and Brooks 1980). Hot-iron branding and toe-clipping expose tissue to infection, while external markers can cause abrasions, entanglement, or compression of tissues (Eagle *et al.* 1984; Nietfeld *et al.* 1994; Baker *et al.* 2001; Wells 2002), and internally placed devices may cause blockage, be rejected from the animal's body, or cause tissue reactions and infection (Eagle *et al.* 1984; Guynn *et al.* 1987; Hernandez-Divers *et al.* 2001; Lander *et al.* 2005; Green *et al.* 2009).

Markers may also increase energy expenditure and impede the animal's ability to perform natural behaviours such as locomotion, feeding or escaping from predators. For instance, penguins (*Pygoscelis* sp.) and green turtles (*Chelonia mydas*) fitted with external data loggers and transmitters experienced drag, which decreased swimming speeds and increased energy expenditure (Bannasch *et al.* 1994; Watson and Granger 1998). Thermoregulatory abilities may be affected; e.g. the attachment of markers to the plumage of mallard ducks (*Anas platyrhynchos*) reduced thermoregulatory abilities (Bakken *et al.* 1996). Markers may also interfere with the performance of natural behaviours; for example, radio-transmitters on mallard ducks interfered with time spent feeding and caused overall weight loss (Pietz *et al.* 1993). Some of these effects might be reduced by using smaller devices. It has been recommended that devices placed on animals should weigh less than 5% of the animal's body mass (Macdonald 1978), while other researchers propose more graded recommendations (between 0.7% and 9%), depending on the study species (Brooks *et al.* 2008).

Pursuit, capture and the pain associated with marking may cause animals to experience fear or anxiety (Hemsworth 2004; Mellor *et al.* 2004). Acute pain responses of cattle (*Bos taurus*) have been studied during hot-iron and freeze branding. Compared with freeze branding, hot-iron branding results in greater escape-avoidance reactions (Lay *et al.* 1992a), as well as a greater incidence of behavioural changes (tail-flicking, kicking and falling) and more prolonged physiological responses (elevated heart rate and plasma concentrations of cortisol and epinephrine; Lay *et al.* 1992a, 1992b; Schwartzkopf-Genswein *et al.* 1997a, 1997b, 1997c, 1998). Weddell seals (*Leptonychotes weddellii*) exhibit a physiological stress response to capture witnessed by elevated cortisol levels; this response is significantly reduced with the administration of the sedative diazepam (Harcourt *et al.* 2010). Pursuit and subsequent capture can also result in capture myopathy in a variety of birds and mammals, resulting in muscle necrosis, metabolic acidosis and myoglobinuria (Spraker 1993; Curry 1999; Herráez *et al.* 2007;). Capture myopathy may also result in death occurring days or weeks after capture and handling (Paterson 2007).

Researchers tend to choose marking and tagging methods they believe will minimise detrimental effects on the animal, although good data on which to base a decision are often lacking (Murray and Fuller 2000). For example, Smith *et al.* (1973) stated that hot-iron branding of ringed seals (*Phoca hispida*) 'caused little apparent distress to the animals', but the authors did not collect measures of distress to substantiate this claim. Similarly, Williams and Siniff (1983) wrote that 'the advantage of the surgically implanted devices [in sea otters (*Enhydra lutris*)] is that they offer no impediment physically or behaviorally', but again the authors provided no data to substantiate this claim. The lack of data on marking effects may reflect the difficulty of

following control (unmarked) animals in the wild or the preconception that these effects are negligible (Baker and Johanos 2002).

Marine mammal research is increasingly relying on marking and tagging individual animals to answer questions about population dynamics (e.g. birth and survival rates), behavioural ecology (e.g. foraging, mate choice) and physiology (e.g. energy requirements) (e.g. Hedd *et al.* 1995; Merrick and Loughlin 1997; Andrews *et al.* 2002; Maniscalco *et al.* 2006). Literature reviews are available that address the potential effects marking devices can have on vertebrates (e.g. Murray and Fuller 2000); however, no review has focussed on effects specific to marine mammals. Additionally, some marine-mammal marking methods have come under increasing public criticism (e.g. Dalton 2005), making a review of this topic especially important.

In the present paper, we review 30 years of published research assessing the effects of different marking and tagging techniques on marine mammals. We also propose guiding principles to minimise the detrimental effects of marking, and recommend specific monitoring and reporting practices to help standardise future work assessing these effects.

Materials and methods

We focussed our review on published, peer-reviewed journal articles pertaining to marking and tagging of marine mammals. We recognise that some studies have been published only in the grey literature (such as e.g. governmental reports, conference abstracts), but did not include this material because of (1) difficulties in uniform access to this material, and (2) the lack of consistent peer-review.

We began our search for relevant articles with Web of Science, IngentaConnect and Google Scholar, using the terms 'marking', 'tagging' or 'transmitter' in combination with the terms 'effect(s)', 'evaluation' or 'response'. Using the articles identified by these searches, we then scanned the literature backwards (using the papers cited in these articles) and forwards (by seeing who later cited these articles) in time, repeating this process every time a relevant article was identified. We evaluated journal articles published between January 1980 and April 2011. This time frame was chosen because of the online availability and reliability of searching services since 1980. We restricted our search to articles that had used markers that uniquely identified individual animals, and excluded articles that had used devices such as the Crittercam (National Geographic Television, Washington DC, USA) and video cameras that do not provide a uniquely identifiable mark.

For the ease of discussion, we use the term 'marking' to include the use of marking devices such as paint or hot-iron brands, radio- and satellite-telemetry devices, as well as data loggers.

Studies were grouped into two categories, namely Categories A and B. Category A studies were designed to show whether a particular marker affects the animal (e.g. assessing wound healing after hot-iron branding), whereas Category B studies tested the feasibility of marking and reported incidentally on the effects on the animal (e.g. successful placement of PIT tags in sea otters). Studies that used markers to study the behaviour of

animals and report incidentally on marking effects (e.g. movement data collected by radio-telemetry devices), that described capture and handling techniques for a particular species (e.g. beluga capture and handling techniques), or that described the frequency of tag loss and its effects on population data were not included in our review. Readers interested in capture and handling effects or tag loss are referred to studies such as Curry (1999), McMahon *et al.* (2005), McMahon and White (2009) and Testa and Rothery (1992).

Studies were then grouped by marking or tagging method, as follows: (1) external tracking or telemetry devices, (2) implanted tags for marking, (3) hot- and cold-iron branding, and (4) visual tags. These groupings were chosen on the basis of how the device was affixed to the animal and the level of tissue manipulation (handling or altering) or tissue damage (removal or destruction) involved. Studies were classified (Table 1) on the basis of the level of tissue manipulation or damage involved, as follows: Minimum – minimum tissue manipulation, but no tissue destruction; Moderate – moderate tissue manipulation or damage; and Severe – severe tissue destruction or damage (categories were designed on the basis of similar levels of invasiveness presented by CCAC's Guidelines for the Care and Use of Wildlife (CCAC 2003). More specifically, the placement of external devices may cause minimal to moderate tissue manipulation or damage; implanted tags have the potential to cause minimal to severe tissue manipulation depending on the placement of the device in the animal; branding causes tissue destruction; and visual tags may cause minimal tissue manipulation or removal depending on the placement of the tags.

Within each marking type, we examined five types of effects that marking devices may have on animals, including (1) behaviour (e.g. changes in swimming behaviours, haul-out behaviour, group structure, migration, trip length), (2) physiology (shorter-term effects, e.g. changes in heart rate, haematology and serum chemistry, cortisol levels, heat flux), (3) injury and disease (e.g. wound healing, tissue damage and histological changes), (4) survival and (5) reproduction and growth (i.e. longer-term physiological effects). The duration of time that the animals retained the marking device (temporary, semi-permanent, or permanent) and the duration of effects (short-term – less than a week; long-term – weeks to years; unknown – authors do not present enough data; and not applicable – no measurable effects) are reported in Table 1 (on the basis of the classification system proposed by Mellor *et al.* 2004).

Results

Types of marking studies involving marine mammals

We identified 39 studies that addressed the effects of marking on marine mammals; 22 of which were published since 2000 (Fig. 1). Most of the 39 studies focussed on behavioural changes and the injuries caused by the placement of the markers; 17 of the 39 studies considered multiple effects (Fig. 2). The majority of studies that addressed behaviour and injury found effects, but the responses varied by marking device and species studied. Most studies on survival did not find an effect, but studies on short-term physiological changes all found an effect of marking.

Studies assessing marking effects on reproduction or growth did not find an effect of marking devices. Of the 39 studies, 24 were in Category A (14 species; Table 1) and 15 in Category B (13 species; Table 1).

Category A – studies designed to test whether marking directly affects the animal

The 24 studies that investigated whether marking directly affects marine mammals focussed primarily on behavioural effects, followed by survival effects and injuries. Multiple effects were investigated in 7 of the 24 studies. Articles assessing physiological changes and tissue injury, all found effects of marking ($n=10$); however, studies investigating marking effects on survival ($n=7$) and reproduction and growth ($n=3$) did not find any effects of marking on the animals. Externally attached radio-transmitters and time-depth recorders were the most commonly studied marker types, and were affixed to the animals in different ways. The effects of visual tags and hot- and cold-iron branding were also studied directly.

Pinnipeds were the most commonly studied group of marked marine mammals (8 of the 14 species studied) – particularly southern elephant seals (*Mirounga leonina*) and Steller sea lions (*Eumetopias jubatus*).

Category B – studies testing the placement of a device

The majority of the 15 studies that evaluated whether placement of a marker caused injury or affected behaviour investigated one or more effects. The two studies that investigated short-term physiological changes found effects of the marking devices. No studies within Category B investigated effects on reproduction or growth. Two of the seven studies that investigated survival effects of marking devices reported a reduction in survival.

Radio and satellite transmitters were the most commonly studied markers (10 of 15 studies). Seven of the transmitter studies involved implanting a device and describing the implantation process and the animal's subsequent reaction. Three other studies tested the effectiveness of the device after deployment. Three studies involved passive integrated transponder (PIT)-tag placement, one involved the placement of an acoustic tag and one involved marking with fluorescent paste.

Sea otters were the most commonly studied species in Category B, most likely because of their declining numbers and the need to develop a marker that does not affect the natural water-repellent pelage of the animal (Hatfield and Rathbun 1996).

Marking and tagging devices used

Four types of marking and tagging methods dominated the marine mammal literature, including (1) external marking devices (16 studies), (2) implanted tags for long-term marking (12 studies), (3) hot- and cold-iron branding (9 studies) and (4) visual tags (7 studies). Studies grouped into Categories A and B showed several commonalities by type of marking method used, with four studies assessing multiple marking devices (Irvine *et al.* 1982; Garshelis and Siniff 1983; Baker and Johanos 2002; Hastings *et al.* 2009).

Table 1. The 39 articles that address the effects of marking on marine mammals

Category A represents articles addressing the direct effects of marking and Category B represents articles testing the effectiveness of a marking device and mentions the effects of the device. Marking method: FB, fluorescent paste; RT, radio-transmitter; FT, flipper tags; TDR, time-depth recorder; PIT, passive integrated transponder; HB, hot-iron branding; FB, freeze-iron branding; B, bleach mark; P, paint mark; and LHX, life-history transmitter. Duration of marking, based on classification proposed by Mellor *et al.* (2004): Temp, temporary; Semi, semi-permanent; and Perm, permanent. Level of tissue damage, categories formed on the basis of guidelines in CCAC (2003): Min, minimal (tissue manipulation, but no tissue destruction); Mod, moderate (moderate tissue manipulation and or tissue destruction); and Sev, severe (severe tissue manipulation or destruction). Measured marking effects: B, behavioural; P, physiological; I, injury and disease; S, survival; and R, reproduction and growth. An asterisk indicates that the authors reported an effect. Duration of reported effects: S, short-term (less than a week); L, long-term (months to years); U, unknown; and NA, not applicable because of no measurable effects. Stats: N, the study did not report the use of statistical analyses; and Y, the study did report some form of statistical analysis in the article. C, captive; W, wild

Author	Species	Number of animals	Marking	Duration of marking	Placement	Method of attachment	Level of tissue damage	Measured effects ⁴	Duration of reported effects	Injury type	Stats	Captive or wild
Category A Irvine <i>et al.</i> (1982)	Atlantic bottlenose dolphin	7 single, 3 double bolt	RT	Semi	Dorsal fin	Bolt	Mod	B*, I*	L	Bolts tore fin, leaving necrotic discolored wounds	N	W
		16	Visual tag	Semi	Dorsal fin	Single bolt	Mod	I*	L	Fin damage	N	W
		19	Visual tag	Semi	Dorsal fin	Double bolts	Mod	I*	L	Skin abrasions, bolt wounds	N	W
		47	FB	Perm	Both sides of dorsal fin; on body below fin	Irons cooled in dry ice	Sev				N	W
		53	Roto tags	Semi	Trailing edge of dorsal fin		Mod	I*	U	Fin damage	N	W
Henderson and Johanos (1988)	Hawaiian monk seal	17	Spaghetti tags	Temp	Rear flipper	Metal screw	Min	I*	L	Entry wounds	N	W
		13	Plastic FT	Semi	between 4th and 5th digit front flipper		Mod	S, B*, I*	L	Tag tore out tearing tissue	Y	W
Trites (1991)	Northern fur seal	200	FT monel metal	Semi	Above dorsal hump	Implanted in skin	Min	R	NA		Y	W
Watkins and Tyack (1991)	Sperm whale	2	Sonar transponder and RT	Perm	Pelage of mid-back		Mod	B	NA		N	W
Walker and Boveng (1995)	Antarctic fur seal	105	TDR and RT	Semi	Dorsal side	Epoxy glued	Min	B*	L		Y	W
Schneider and Bard (1998)	Bottlenose dolphin	10	RT (VHF) and TDR	Temp/Semi	Dorsal side	Suction cup	Min	B*	S – only report acute response		N	W
Hanson and Bard (1998)	Dall's porpoise	13	RT	Temp/Semi	Dorsal side	Suction cup	Min	B*	S – only report acute response		N	W
Hooker <i>et al.</i> (2001)	Northern bottlenose whale	47	RT (VHF) and TDR	Temp/ Semi	Dorsal side	Suction cup	Min	B*	S – only report acute response		Y	W
Baker and Johanos (2002)	Hawaiian Monk seal	56	Satellite TDR	Semi	Dorsal pelage	Epoxy glued	Min	S, B	NA		Y	W
		8	TDR	Semi	Dorsal pelage	Epoxy glued	Min	S, B	NA		Y	W
		5	GPS data logger	Semi	Dorsal pelage	Epoxy glued	Min	S, B	NA		Y	W
		437	Plastic flipper tags	Semi	Rear flipper		Min	S, B	NA		Y	W
Geersten <i>et al.</i> (2004)	Harbor porpoise	1	Satellite and RT (VHF)	Semi	Dorsal fin	3 holes bored in fin, fixed with pins and nuts	Mod	B*, P*, I*	S – tags only attached for 7 d	Reddish exudate at attachment site	Y	C

van den Hoff <i>et al.</i> (2004)	Southern elephant seal	2466	HB	Perm	Right and left flank	Hot-iron	Sev	I*	L – most healed within a year	Brand wound	Y	W
Daoust <i>et al.</i> (2006)	Harbor seal	306	HB and FB	Perm	Mid-region of back	Hot-iron; liquid nitrogen cooled iron	Sev	I*	L	Brand wound	Y	W
Martin <i>et al.</i> (2006)	Amazon river dolphin	51	RT	Semi	Dorsal fin	Steel borers	Mod	S, R, I*	Y	Holes and wounds where pins were	Y	W
McMahon <i>et al.</i> (2006b)	Southern elephant seal	14050	HB and FB	Perm	Each side of caudo-dorsal flank	Hot-iron; liquid nitrogen or dry ice cooled iron	Sev	S	NA		Y	W
Mellish <i>et al.</i> (2007a)	Steller sea lion	6	LHX	Perm	Ventrocaudal abdominal cavity	Intrapertitoneal cavity, free-floating	Sev	B, P*	L – return to baseline at 6 weeks post-implant		Y	Semi C
Mellish <i>et al.</i> (2007b)	Steller sea lion	7	HB	Perm	Left shoulder/flank	Hot-iron	Sev	P*	L – return to baseline 7–8 weeks post-brand		Y	C
McCafferty <i>et al.</i> (2007)	Grey seal	2	Heart-rate transmitter and recorder	Semi	Dorsal side	Velcro patches epoxy glued to pelage	Min	P*	U		Y	C
McMahon <i>et al.</i> (2008)	Southern elephant seal	124	TDR, RT (VHF), and platform transmitter terminals	Semi	Dorsal side	Epoxy glued to pelage	Min	S, R	NA		Y	W
Eskesen <i>et al.</i> (2009)	Harbour porpoise	8	Satellite transmitters	Semi	Dorsal fin	3 holes bored in fin, fixed with pins	Mod	P*	U		Y	W
Hastings <i>et al.</i> (2009)	Steller sea lion	4	FB	Perm	On side below dorsal fin	Liquid nitrogen cooled iron	Sev	P*	U		Y	W
Walker <i>et al.</i> (2009)	Steller sea lion	366	HB, FT	Perm	Dorsal side, fore flippers	Hot-iron	Sev	S	NA		Y	W
Walker <i>et al.</i> (2010)	Steller sea lion	9	LHX	Perm	Ventrocaudal abdominal cavity	Intrapertitoneal cavity, free-floating	Sev	B*	L – did not monitor past 12 days		Y	Semi C
Walker <i>et al.</i> (2010)	Steller sea lion	11	HB	Perm	Left shoulder/flank	Hot-iron	Sev	B*	S – did not monitor past 3 days		Y	Semi C
Paterson <i>et al.</i> (2011)	Gray seal	39	Plastic FT	Semi	Hind flippers		Min	I*	S – monitored 29 days post	Exudate, swelling, open	Y	W
Wilkinson <i>et al.</i> (2011)	New Zealand sea lion	135	HB	Perm	Left shoulder and flank	Hot-iron	Sev	S	NA		Y	W

(Continued next page)

Table 1. (*Continued*)

Author	Species	Number of animals	Marking	Duration of marking	Placement	Method of attachment	Level of tissue damage	Measured effects ⁴	Duration of reported effects	Injury type	Stats	Captive or wild
Category B Garshelis and Siniff (1983)	Sea otter	3	RT	Semi	Neck	Collar	Min	S*, I*	L	Neck constriction	N	W
		6	RT	Semi	Ankle	Ankle bracelet	Min	S*, I*	L	Swollen ankle	N	Both
		144	RT	Semi	Rear flipper	Steel bolts and nuts	Mod	S, B*, I*	L	Broken digits, slits in webbing	N	W
		10	RT	Perm	Ventrally, below umbilicus	Subcutaneous	Mod	S*, B*, I*	U	Removed sutures, exposed device	N	W
Mate and Harvey (1983)	Gray whale	14	RT	Perm	1 m behind blowhole	Intraperitoneal sutured to abdominal musculature	Mod	B, I*	L	Swelling at entry site – 13 days after tag attachment	N	W
	Sea otter	5	RT	Perm	Ventrally, below umbilicus	Subcutaneous	Mod	S*, I*	S	Contusion abdominal wall, haemorrhage subcutaneous, infection, suture removal	N	W
Griben (1984) Thomas <i>et al.</i> (1987)	Northern fur seal	2535	FP	Temp	Head and back	Pelage	Min	I, B	NA	No injury noted	N	W
	Sea otter	6	PIT tags	Perm	Base of neck top of shoulders	Subcutaneous	Mod	I	NA	No migration, infection or tissue damage noted	N	C
Ralls <i>et al.</i> (1989)	Sea otter	40	RT	Perm	Ventrally, below umbilicus	Intraperitoneal cavity, sutured to peritoneum	Sev	S, I	NA	No injury noted	N	W
Goodyear (1993)	North Atlantic right whale	13	Sonic transmitter; VHF radio-transmitter	Perm	Back	Implanted in blubber	Mod	B*	S		N	W
Humpback whale		4	Sonic transmitter; VHF radio-transmitter	Perm	Back	Implanted in blubber	Mod	B*	S		N	W
Hatfield and Rathbun (1996)	Sea otter	75	RT	Semi	Hind flipper		Min	S(?), B*, I*	U	Tags tore flipper webbing	Y	W

Wright <i>et al.</i> (1998)	Manatee	5	PIT tags	Perm	Middle of freeze brand	Subcutaneous	Mod	I*	L	Injection sites raised and hard, then became flat	N	C
Mulcahy and Garner (1999)	Polar Bear	7	Satellite transmitter	Perm	Dorsal cervical area	Subcutaneous	Mod	I*	L	Sutures broken, leaving gaps at exudate drainage	N	W
Galimberti <i>et al.</i> (2000)	Southern elephant seal	510	PIT tags	Perm	Rear flipper	Subcutaneous	Mod	S, I	NA	No tissue reaction observed	Y	W
Blomqvist and Amundin (2004)	Bottlenose dolphin	2	Acoustic tag	Temp/Semi	Dorsal fin	Suction cup	Min	B*	U – tags were only temporarily attached		Y	C
Lander <i>et al.</i> (2005)	Harbor seal	15	RT encased in resin or wax	Perm	Left dorsal thorax	Subcutaneous	Mod	S(?), P*, I*	L – tissue reaction resin RT; S- wax RT	Wound discharge and opening	N	Both
Horning <i>et al.</i> (2008)	California sea lion	4	LHX	Perm	Ventrocaudal abdominal cavity	Intraperitoneal cavity, free-floating	Sev	S, B*, I*	S	Minimal swelling at incision site	N	Semi C
	Steller sea lion	15	LHX	Perm	Ventrocaudal abdominal cavity	Intraperitoneal cavity, free-floating	Sev	S, B*, I*	S	Minimal swelling at incision site; mild clear discharge noted in 2 animals	N	Semi C
Green <i>et al.</i> (2009)	California sea lion	3	Heart-rate data logger	Perm	Right thoracic and lumbar flank	Subcutaneous	Mod	I, P*	S	Minimal swelling and no exudate	N	Semi C – rehab
	Northern elephant seal	3	Heart-rate data logger	Perm	Right thoracic and lumbar flank	Subcutaneous	Mod	I*, P*	L – removed implant due to rejection	Presented with swelling and pus and mucus exudate	N	Semi C – rehab

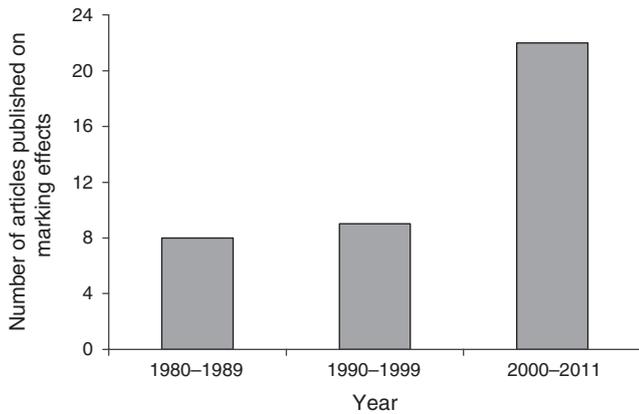


Fig. 1. Number of studies published on marking effects between January 1980 and April 2011.

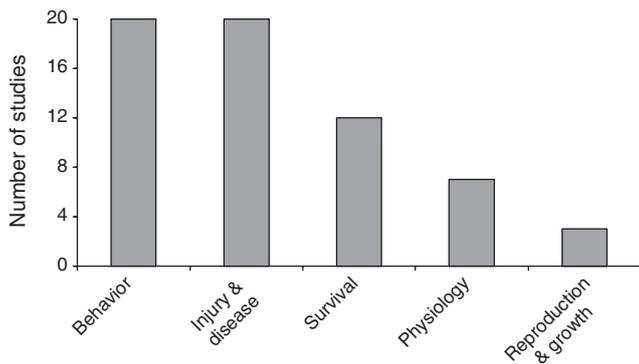


Fig. 2. Effects of marking as reported in the 39 identified articles (Table 1). Seventeen of the studies reported multiple effects.

(1) External marking devices

Marking devices can be secured to marine mammals through a body part (e.g. cetacean transmitter attachment using pins placed through the dorsal fin or ridge), with suction cup tags (also referred to as remora tags), by placing it around the animal's neck or ankle, or by gluing the device to the animal's pelage. In all, 13 of the 16 studies assessing the attachment of external devices, such as radio-transmitters and time-depth recorders, focussed on behavioural effects. Short-term physiological effects ($n=3$), injuries ($n=7$), survival ($n=4$) and reproductive and growth rate effects ($n=2$) were addressed in fewer studies.

Non-lethal firing of projectiles is commonly used to attach devices to cetaceans. Cetacean behavioural responses to the attachment of external devices has included aberrant swimming behaviour when attached through the dorsal fin using bolts (Irvine *et al.* 1982), changes in the frequency of leaps and group speed after suction-cup attachment (Schneider and Baird 1998), and flinching, tail slapping, rapid swimming and surfacing attempts after suction-cup attachment (Hanson and Baird 1998; Hooker *et al.* 2001; Blomqvist and Amundin 2004). External devices deployed by implantation into the skin

or blubber of whales have shown minimal behavioural effects, including skin-twitches, followed by shallow dives or no response (Mate and Harvey 1983; Watkins and Tyack 1991; Goodyear 1993), or breaching and rapidly accelerating on tagging (one whale, Goodyear 1993). Some whales reacted to missed tagging attempts by swimming away, raising their heads or backs out of the water, defecating and quickly submerging – perhaps in response to the splash the device made in the water (Watkins and Tyack 1991). One study concluded that anchors used to attach the tags did not cause severe damage; one whale that lost its tag showed swelling, but no sign of laceration, around the tag-entry point (Mate and Harvey 1983).

Most studies examining the behavioural effects of external devices on cetaceans were conducted in the wild and did not record pre-tagging behaviour. One exception was a study on a single harbor porpoise (*Phocoena phocoena*; Geersten *et al.* 2004) that reported changes in log-rolling behaviour, roll duration, dive duration, daily food intake and surfacing areas after a radio-transmitter was attached through the dorsal fin.

Epoxy glue has been used in four studies to attach external devices to the pelage of animals (Walker and Boveng 1995; Baker and Johanos 2002; McCafferty *et al.* 2007; McMahan *et al.* 2008). Their thermosetting components have the potential to cause thermal burns and react with skin, but no published study has addressed these effects.

Studies of marked marine mammals have tended to focus on effects such as maternal foraging and attendance behaviour (Walker and Boveng 1995) and survival and migration (Baker and Johanos 2002). For example, Antarctic fur seals (*Arctocephalus gazella*) fitted with both time-depth recorders and radio-transmitters had increased foraging-trip and nursing-visit durations compared with animals carrying only radio-transmitters (Walker and Boveng 1995). Another study using devices attached with epoxy glue examined the effects of research handling, including blood sampling, flipper tagging and the placement of time-depth recorders, data loggers and video recorders, on the migratory behaviour, survival and body condition of Hawaiian monk seals (*Monachus schauinslandi*), and found no difference between control and handled animals (Baker and Johanos 2002). There was, however, no direct assessment of how the attachment of devices affected the behaviour or foraging success of the animals.

Alternative methods of attaching devices include neck and ankle collars. These methods of attachment were found to be detrimental to sea otters, causing severe constriction and one death attributable to the device (Garshelis and Siniff 1983). Flipper transmitters were believed to be the least likely to harm animals, but effects on survival could not be determined. Flipper transmitters did result in injuries (broken middle digits and slits in the webbing of the otter's flipper) and altered behaviour (otters pulled at the transmitter and held their flipper out of the water), and were typically lost within 3 months (Garshelis and Siniff 1983). The authors tested the effectiveness of their device by using 144 sea otters fitted with radio-transmitters placed on their rear flipper with the use of steel bolts. In another flipper-attachment study, 22 of 75 tagged otters were never seen again, and 18 of the 53 otters that were seen after tagging had sustained flipper damage

because of the transmitter attachment (Hatfield and Rathbun 1996). Flippers carrying transmitters were seen drooping unnaturally at the tip, perhaps as a result of increased drag.

Other studies assessing survival and reproduction after the placement of an external marking device have found no effect (Baker and Johanos 2002; Martin *et al.* 2006; McMahon *et al.* 2008). These results may be specific to the particular marking devices and species tested, and therefore should be interpreted with caution. When considering novel techniques or use on a different species, preliminary studies are encouraged before wide-spread use or deployment. The animals used in these studies may have been particularly robust (as suggested by Martin *et al.* 2006); however, McMahon *et al.* (2008) assessed effects during varying environmental conditions and over a range of seal sizes and between sexes, and found no marking effects. Results may also vary with environmental conditions, which should be evaluated before commencing full-scale marking programs.

Three studies reported on the short-term physiological effects of the attachment of external marking devices. These studies found changes in temperature distribution around the attachment site (McCafferty *et al.* 2007), as well as a reddish exudate at the attachment site (Geersten *et al.* 2004). One study recorded increased heart rate in grey seals at the time of device attachment (McCafferty *et al.* 2007). Boring holes into the dorsal fin of harbour porpoises caused variation in heart rate and decreased respiration (Eskesen *et al.* 2009).

(2) Implanted tags

One limitation of external attachment of telemetry devices on aquatic mammals is the high rate of instrument loss as a result of physical damage and annual molts, typically limiting the monitoring of marked animals to weeks or months. Longer-term monitoring may require implanting devices into the animal, e.g. through intraperitoneal or subcutaneous placements.

In all, 3 of the 12 studies on internal devices investigated behavioural effects (Mellish *et al.* 2007a; Horning *et al.* 2008; Walker *et al.* 2009), three investigated physiological effects (Lander *et al.* 2005; Mellish *et al.* 2007a; Green *et al.* 2009) and four examined effects on survival (Williams and Siniff 1983; Ralls *et al.* 1989; Galimberti *et al.* 2000; Horning *et al.* 2008). In all, 9 of the 12 studies assessed the impacts of internal marking devices on injury and disease. No studies have investigated the effects of internal placement of marking devices on reproduction or growth.

Developments in technology have allowed researchers to track animals for longer periods. For example, the Life History Transmitter (LHX tag) allows life-long data to be collected on dive behaviour, pressure, motion, light levels, temperature and conductivity (Horning and Hill 2005). Three studies have investigated the effects of intraperitoneal implantation of LHX tags in sea lions (Mellish *et al.* 2007a; Horning *et al.* 2008; Walker *et al.* 2009). Horning *et al.* (2008) examined the feasibility of the surgical technique used for implanting LHX tags in California sea lions (*Zalophus californianus*) and Steller sea lions. All sea lions recovered well after surgery, with minimal swelling around the incision site. Physiological effects of the implantation included increased levels of acute-phase proteins

(i.e. indicators of infection, inflammation or tissue trauma) at 2 weeks post-surgery, with levels returning to baseline within 6 weeks (Mellish *et al.* 2007a). Dive behaviour recorded post-release showed that LHX-implanted individuals had dive depth, duration, frequency and dispersal distances similar to those of free-ranging non-LHX-tag individuals (Mellish *et al.* 2007a).

The first study to address pain in a marine mammal was conducted on Steller sea lions after LHX abdominal surgery (Walker *et al.* 2009). Behavioural responses in the days after abdominal surgery included changes in back arching, standing, locomotion, time alert, lying time, and time spent with pressure on the belly. Sea lion behaviours were still affected 12 days after surgery suggesting the need for more effective analgesic methods for this procedure.

Several studies have looked at the feasibility of placing internal devices, including subcutaneous and internal placement of radio-, satellite- and sonic transmitters (Garshelis and Siniff 1983; Williams and Siniff 1983; Mulcahy and Garner 1999; Lander *et al.* 2005; Green *et al.* 2009) and PIT tags (Thomas *et al.* 1987; Wright *et al.* 1998; Galimberti *et al.* 2000). The first attempts to implant subcutaneous radio-transmitters were with sea otters, some of which died within 2–5 days after implantation (Garshelis and Siniff 1983; Williams and Siniff 1983). One necropsy revealed a contusion on the abdominal wall, with subcutaneous hemorrhaging, and led to the recommendation that radio-transmitters be placed in the intraperitoneal cavity (Williams and Siniff 1983). The authors speculated that this placement would not impede the otter physically or behaviourally, but no data were provided to test this claim. In another study, 5 of 40 sea otters implanted intraperitoneally with radio-transmitters died within 223 days of the surgery (Ralls *et al.* 1989), but the authors found no evidence of adhesions or intestinal obstructions on necropsy.

The subcutaneous implantation of radio- and satellite-transmitters has been reported in polar bears (*Ursus maritimus*; Mulcahy and Garner 1999) and harbor seals (*Phoca vitulina*; Lander *et al.* 2005). Results showed that implantation caused exudate drainage and discharge to varying degrees. In the harbor seal study of Lander *et al.* (2005), the radio-transmitters were either encapsulated in a physiologically compatible wax coating or an inert resin. Wound healing varied; animals implanted with the resin-coated transmitters were more likely to develop wound discharge and openings near the incision, requiring antibiotic treatment, than were animals implanted with the wax-coated transmitters. The presence of exudate was witnessed in the days after implantation, with wounds healing at 10 days post-implantation. The length of time that exudate was present, and the completion of wound-healing, were not reported for the resin-coated transmitter. No effects on post-implantation survival were noted.

Techniques and transmitters have evolved since implantation studies in marine mammals began in the 1980s, but relatively little attention has been devoted to considering whether implanted devices are biologically compatible with the study species (e.g. Hori *et al.* 2009). One study implanted heart-rate loggers into pinnipeds and found very different responses between California sea lions ($n=3$) and northern elephant seals (*Mirounga angustirostris*; $n=3$) (Green *et al.* 2009). The sea lions had

little swelling and no exudate after implantation, but all three elephant seals showed an inflammatory response and the data loggers were removed.

PIT tags are another method used to individually identify animals, and consist of an electromagnetic coil and microchip (programmable with a unique code) that emits a signal when scanned with electromagnetic energy (Nietfeld *et al.* 1994). The tags are placed subcutaneously and can be read by a receiver placed close to the individual (e.g. within 20 cm). PIT-tag placement and response has been successfully measured in sea otters (Thomas *et al.* 1987), manatees (*Trichechus manatus*; Wright *et al.* 1998) and southern elephant seals (Galimberti *et al.* 2000). No tissue reactions to tag placement were found in sea otters and southern elephant seals, nor have differences been noted in survival between PIT-tagged and non-PIT-tagged individuals (Galimberti *et al.* 2000). PIT-tag injection sites in manatees were slightly raised and hard, with minor scarring present (Wright *et al.* 1998). However, the manatees were also freeze-branded and the PIT tags were injected in the centre of a freeze-branded area – this combination may have produced the tissue reaction.

(3) *Hot- and cold-iron branding*

Cattle and horses have been branded for centuries (Macpherson and Penner 1967). Branding has been modified for use in other mammals such as seals and sea lions and non-domesticated ungulates (Nietfeld *et al.* 1994; Merrick *et al.* 1996). Branding can provide a mark that remains visible throughout the animal's life. There has been debate as to whether branding should be used as a marking method for marine mammals. Public concern has prompted lawsuits and the revocation and suspension of research permits for hot-iron branding of some pinniped species (Green and Bradshaw 2004; Dalton 2005).

Hot-iron branding uses metal branding irons of various letters, numbers or shapes that are heated until red hot and then applied to the animal's skin for 2–7 s (Erickson *et al.* 1993; Merrick *et al.* 1996; Wells 2002). Hair may be removed before application and the branded site wiped dry to facilitate a clear uniform brand (Gentry and Holt 1982; Erickson *et al.* 1993). The areas commonly branded are the upper shoulder or back on pinnipeds, and the dorsal fin on dolphins (Nietfeld *et al.* 1994; Wells 2002). Animals are sometimes branded while under general gas anaesthesia. Both hot-iron and freeze branding have been studied in cattle (Lay *et al.* 1992a, 1992b; Schwartzkopf-Genswein *et al.* 1997a, 1997b, 1998), and a few studies have addressed the physiological effects of branding in pinnipeds (Daoust *et al.* 2006; McMahon *et al.* 2006b; Mellish *et al.* 2007b).

In freeze branding, irons are cooled in a dry ice–alcohol solution to -79°C or with liquid nitrogen to approximately -200°C and are held in place on the animal for 20–60 s (Macpherson and Penner 1967; Nietfeld *et al.* 1994; Daoust *et al.* 2006). While hot-iron brands burn through the dermal layers and disrupt the hair follicles preventing new hair growth, freeze branding damages the pigment-producing melanocytes but leaves the hair follicles intact allowing for regenerative growth of white hair (Macpherson and Penner 1967; Nietfeld

et al. 1994; Wells 2002; Daoust *et al.* 2006). The results of the different branding methods vary by species. Studies on cattle indicate that freeze branding causes less acute pain than hot-iron branding (Lay *et al.* 1992a, 1992b; Schwartzkopf-Genswein *et al.* 1997a, 1997c).

Seven studies have examined the effects of branding in four marine mammal species. One of these studies assessed the physiological responses to branding (Mellish *et al.* 2007b), two assessed injuries and wound healing following branding (van den Hoff *et al.* 2004; Daoust *et al.* 2006) and three assessed survival (McMahon *et al.* 2006b; Hastings *et al.* 2009; Wilkinson *et al.* 2011). One study has investigated the behavioural effects of branding (Walker *et al.* 2010), but no study has investigated how branding affects growth and reproduction.

Sea lions display pain-related behaviours after hot-iron branding (Walker *et al.* 2010). Specifically, in the 3 days after branding, sea lions spend more time grooming their branded area, less time with pressure on their branded side, and less time in the pool and in locomotion. These results suggest that alternative analgesia protocols are required to help mitigate the pain.

Branding juvenile Steller sea lions with hot-irons produces a systemic inflammatory response as evidenced by changes in peripheral blood values, with levels returning to baseline 7–8 weeks post-branding (Mellish *et al.* 2007b). The study by Mellish *et al.* found no differences in serum cortisol concentrations; however, the initial rise may have been missed, because cortisol was sampled only 90 min after branding. Detecting a peak in cortisol concentrations requires repeat samples at a frequency representative of the pattern of the entire response.

Wound healing patterns vary among species (van den Hoff *et al.* 2004; Daoust *et al.* 2006). Among hot-iron branded southern elephant seal pups, a strong positive correlation was noted between brand-wound healing, brand readability and peripheral skin damage (van den Hoff *et al.* 2004). Brands with more peripheral skin damage had longer healing times, but most brands were completely healed within 1 year, with the molting process contributing to the healing process. In harbor seal pups, cold-iron brands healed faster, but hot-iron brands provided a more permanently legible brand (Daoust *et al.* 2006). Prolonged wound healing of brands may cause pain and affect behaviour; however, no study has addressed these issues.

Effects of branding on survival have been studied in southern elephant seals (McMahon *et al.* 2006b), Steller sea lion pups (Hastings *et al.* 2009) and New Zealand sea lions (Wilkinson *et al.* 2011). No difference was detected in the survival of branded (hot or cold) elephant seals compared with individuals that were only flipper tagged, but none of the cold-iron brands were readable within 1 year of branding (McMahon *et al.* 2006b). Wilkinson *et al.* (2011) tested the efficacy of using hot-iron brands for identifying individual sea lions. In a 10-year period, surviving animals with hot-iron brand marks were identifiable by their marks, showing that brands can be used as a long-term identification tool. Survival rates were similar in branded and tagged-only individuals. A study assessing the survival of Steller sea lion pups in the 12 weeks after branding estimated that mortality attributable to branding was 0.5–0.7% (Hastings

et al. 2009). Overall survival for the 12 weeks post-branding was estimated at 0.868 and varied little with sex, year and capture area.

(4) Visual tags

Tags varying in colour, shape, material (plastic, aluminum, steel or other alloy) and size have been used to visually identify marine mammals. Some tags are self-locking and others use rivets to attach to the animal. The types of tags used depend on resight requirements and whether they will be placed inter-digitally on the flippers, in the axillary webbing, on the dorsal fin or through the animal's ear. Three of six studies designed to evaluate visual tags have investigated behavioural effects, four on injury and disease, and three on survival effects. Only one study has examined growth and none has investigated short-term physiological effects.

Only one of the three studies assessing the behavioural responses to visual tags found an effect of marking. Tagged Hawaiian monk seals hauled out further from the marking site than did untagged animals (Henderson and Johanos 1988). Another study showed that migration rates of Hawaiian monk seals were not influenced by flipper tagging (Baker and Johanos 2002). Similarly, there was no segregation or rejection between unmarked northern fur seals and animals marked with fluorescent pelage paste (Griben 1984).

No study has found that visual tags affect survival (Hawaiian monk seals: Henderson and Johanos 1988; Baker and Johanos 2002; Steller sea lions: Hastings *et al.* 2009). However, visual tags can cause destruction of tissue at the site of tag attachment (Irvine *et al.* 1982) and have been known to cause subsequent tissue damage when torn out (Henderson and Johanos 1988). Paterson *et al.* (2011) used infrared thermography to monitor the healing process after the attachment of flipper tags in grey seals and found small increases in surface temperature during the healing process, with some animals presenting with exudate, swelling and partially open wounds; 24 days after tagging, these signs were no longer present. Paint was not reported to cause histological abnormalities in a single study comparing tissue biopsies of painted and unpainted regions from northern fur seals marked with fluorescent paste (Griben 1984).

Trites (1991) re-evaluated data collected from 1957 to 1966 to determine whether flipper tagging and marking by slicing off the flipper tip affected growth rates in northern fur seal pups (*Callorhinus ursinus*). A previous assessment of the data by Abegglen *et al.* (1957) concluded that marking reduced growth rates, but Trites (1991) found that tagged and untagged pups grew at the same rate and suggested that differences in weight may have been due to inadvertently selecting smaller pups that were more easily captured.

Discussion and research recommendations

Of the 39 studies that specifically addressed marking and tagging, over half (22) were published since 2000. The trend may be due to increased public criticism of different marking devices, as with the hot-iron branding controversy (Green and Bradshaw 2004; Dalton 2005). Researchers are also likely becoming more aware of the potential effects of marking and tagging methods on the populations they study and, in particular,

on the welfare of individual animals (Fraser 1999). In the past 11 years, more research has focussed on assessing the direct effects of marking devices (17 of the 24 studies from Category A, compared with 5 of the 15 studies from Category B).

For a variety of reasons, studies that fail to find treatment differences are less likely to be published, meaning that the published literature is a biased sample of all research conducted on the topic (Csada *et al.* 1996). Thus, we caution readers that our review (and indeed any review) is likely to be biased towards studies that report at least some treatment differences; other studies may have failed to find differences but were not published.

What does the current research show?

Effects of marking have been assessed at the level of an individual animal (e.g. behavioural reactions or injury) and the population level (e.g. survival). Effects reported varied both in length of time present (e.g. days to months) and severity of effects (e.g. from behavioural changes to death). Research on the effects of externally attached devices on marine mammals has shown short-term behavioural reactions (e.g. changes in swimming behaviours) and injury from placement of the device (e.g. bolt migration, constriction and swelling at attachment site). With the exception of one sea otter study, the studies assessing the effects of external devices on survival have shown no effects on survival. Studies on internal devices have shown short-term physiological responses (e.g. increased acute-phase proteins), injuries (e.g. subcutaneous hemorrhaging and wound discharge) and short-term pain responses. The placement of internal devices has shown decreased survival in some species. Studies on hot- and cold-iron branding have also shown short-term physiological effects (e.g. elevated white blood-cell counts, platelets and acute phase proteins) and injury (e.g. delayed wound healing and tissue damage). Pain responses in individuals persist in the days following branding, but there have been no reports of decreased survival as a result of branding. Research on visual tags has shown individual behavioural effects (e.g. changes in haul-out behaviour) and injury (e.g. tissue damage because of tag loss, skin abrasions), but no effects on survival or growth.

Where are the gaps in the literature?

There have been numerous requests for studies to assess the effects of marking on marine mammals (see Seber 1982; Murray and Fuller 2000; McMahon *et al.* 2006a; Beausoleil and Mellor 2007). Permit-granting agencies often require a discussion of the research techniques employed, requiring some analysis of marking effects. Wilson and McMahon (2006) suggested that 'measures to quantify the stress of capture and device attachment in wild animals should routinely be included in proposals for field work'.

It is important to recognise the effects that marking and capture devices can have on the individual animal. Major gaps exist in understanding whether marking devices impede natural behaviours such as movement and feeding patterns, growth, and health, and whether marine mammals experience pain and distress during and after marking. The studies on marker effects on marine mammals have mainly focussed on the

immediate effects on behaviour and injury. Equally important are the effects that marking can have on populations, including effects on reproduction and survival.

The published research on marking effects is inconsistent in how findings are reported and in the description of study designs. There is no standardised method for reporting marking procedures and effects in marine mammals. For example, only 23 of the 39 studies we reviewed reported whether the data were subjected to any kind of statistical analysis (Table 1).

Future studies should include clearly stated research questions or hypotheses, along with complete methodologies and statistical tests. We also suggest that future research should endeavour to use the fewest number of animals to meet research objectives (i.e. power analyses should be conducted) and that marking methods be tested on a subset of animals before larger-scale deployment.

Pain management protocols used during the marking procedure were mentioned only in a few more recent studies, even though 27 of the 39 studies were classified as involving moderate to severe levels of tissue manipulation and destruction. Wildlife care and use guidelines, such as those of the Canadian Council on Animal Care, recommend that researchers use analgesia and anaesthetics for invasive procedures (CCAC 2003). If pain is present because of research-related injury, then researchers should attempt to reduce this. Pain can also affect many aspects of an animal's normal functioning, so reducing animal pain at the time of marking or tagging has the potential to improve the quality of the scientific data.

Where to go from here?

The studies reviewed above reveal limitations associated with the different marking methods, and suggest that researchers need to assess the cost to the animal when considering marking methods. Factors to consider are the length of time the marker lasts on the animal (influenced by the loss of the tag over time from being ripped out or falling off because of molting, and by living conditions of the animal), as well as transmitter malfunction and battery life. Complications from capture and handling or anaesthesia, as well as the resources required for effective follow up, also need to be considered. For example, researchers may choose to use external marking devices knowing that they are going to fall off during moulting to avoid the longer-term or more invasive consequences of implanting internal devices. Internal implantation of transmitters is an effective way to overcome transmitter loss as a result of molting, but requires surgery and longer handling times.

The effects of marking on animals can vary from more immediate behavioural effects, such as changes in swimming patterns which may have no further consequences, to reduced survival. Marking devices may cause other biological consequences that may reduce the quality of life of the animal for days after the marking procedure (e.g. pain following branding). Such consequences need to be weighed against the overall goal of the marking program.

It is important that the marker placed on the animal does not confound data collection and interpretation. Some researchers recognise that proper analysis of marking effects is needed to be confident that data collected from the marked individual are

representative of the unmarked individuals in the population (e.g. Irvine *et al.* 1982). Unfortunately, it is often difficult to follow unmarked individuals in the wild. Studies comparing unmarked and marked animals can be conducted in a captive setting or where natural markings are distinguishable on individual animals (e.g. sea lions individually identifiable through unique scars, fungal patches, or other distinct markings, Maniscalco *et al.* 2006; grey seals identified by natural pelage markings, Vincent *et al.* 2001; small cetaceans identified by natural markings, Wursig and Jefferson 1990). Mate *et al.* (2007) gave an account of one laboratory's experience with the development of satellite-monitored radio-tag technology for whales. Similarly, the LHX studies (Mellish *et al.* 2007a; Horning *et al.* 2008; Walker *et al.* 2009) have used a variety of approaches to understand the impact of the device on the animals. Recent work by Field *et al.* (2011) focussed on minimising the impacts of tracking devices used on phocid seals by refining instrument-attachment techniques. These studies provide good models for future research on the effects of marking procedures.

Telemetry devices are becoming more accessible to wildlife researchers. However, the body may reject implanted devices (e.g. Lander *et al.* 2005; Green *et al.* 2009), especially when they are not encased in biocompatible material. The transmitter housing may break, causing battery leakage inside the animal and eventual tag failure. Most studies do not report on the biocompatibility of materials used to encase the tags. Future studies should report material biocompatibility for the study species and marking device used.

Tagging methods that are successful on one species may not work well on other species, such as heart-rate data loggers that were rejected in elephant seals but not in sea lions (Green *et al.* 2009). Stage of life can also affect marking success. For example, animals instrumented during critical periods, such as lactation, may exhibit different behavioural and physiological effects (Walker and Boveng 1995). Study design needs to consider life-history stage of the animal and how this can affect both the animal and the data collected. Recent research has focussed on the development of tags used in cetaceans through the use of computer simulations (Pavlov *et al.* 2007). This technique allows for a tag to be developed that minimises the overall impact on the animal and potentially allows researchers to obtain higher-quality data. Tags built in this fashion should still go through test periods and biocompatibility trials before large-scale deployment.

Guiding principles for minimising marking impacts

Existing guidelines to minimise the impact of a mark on an individual, while ensuring reliable identification, include the following six criteria: (1) the marking should cause little or no effect on the animal's anatomy and physiology, in both the short and the long term (e.g. the animal should not experience pain or distress, prolonged wound healing time or disease), (2) the marking should not interfere with the animal's ability to perform its natural behaviour, including foraging, breeding and locomotion, (3) the marking should be readable and visible, (4) the marking should not attract predators or affect potential mates or other conspecifics, (5) the mark should persist long enough to meet the research objectives and (6) extensive

handling should be avoided when applying marks (Cook 1943; Friend *et al.* 1994; Nietfeld *et al.* 1994; Murray and Fuller 2000; van den Hoff *et al.* 2004).

Additionally, we propose the following: (7) the fewest number of animals should be marked to meet the research objectives (i.e. power analyses should be conducted, and reported, to determine appropriate sample sizes before marking), (8) a pain management plan should be developed, potentially including the use of appropriate anaesthesia and post-operative analgesics, (9) the marking device should be tested on a subset of animals in the study species before larger-scale deployment, (10) the marked population should be compared with an unmarked control population (e.g. using natural markings on the animal's pelage) or research should conduct observations before and after a marking procedure, whenever possible, to document marking effects, and (11) markings should be carried out only by trained individuals skilled in the marking procedure.

We also recommend that future studies consider monitoring and reporting the following things when conducting marking- and tagging-effect studies on marine mammals: (1) methods used to select sample size, (2) issues with restraint or application of the device or mark, (3) anaesthetic and analgesia agents used (if none was used then provide justification), (4) why the researchers chose the tag or mark as appropriate for their research objectives and whether there are alternative, less invasive methods available (i.e. were the three Rs of research – replacement, refinement and reduction – considered; Russell and Burch 1959), (5) complete methodology for the placement of marking device, in addition to any additional tissue or blood sampling that occurred during the handling procedure, (6) the total time the animal was handled including the placement of the device, (7) the total time spent monitoring the animal, (8) the level of invasiveness of the procedure on the basis of the degree of tissue manipulation or destruction, and (9) the statistical analyses conducted on the data. We agree with Hooker *et al.* (2007) that researchers should be encouraged to publish results of both best practices *and* results that were less favourable (i.e. negative impacts on the animal or the data), because these data may otherwise go unpublished.

Conclusions

To summarise, our review shows that (1) research on marker effects has primarily focussed on short-term behavioural responses, (2) few studies have addressed the effects of markers on reproduction or growth, (3) only two studies have addressed short-term pain caused by marking, (4) no studies designed to show the effects of markings on survival have demonstrated reduced life-expectancy as a result of marking and (5) all studies looking at short-term physiological changes reported measurable effects. Standardising reports with added detail on methodology and sampling design will assist others in implementing best practices when marking and tagging marine mammals. Future research on marine mammals under controlled conditions is required to document acute effects of marking, including pain and distress, and to better understand longer-term effects on health and disease, growth, reproduction and survival.

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