NEW ZEALAND
PENGUIN
INITIATIVE

Marking of Kororā / Little penguins

Discussion paper

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Executive summary

Marking of individual penguins has a long history (about 120 years) and is required for enumeration of a population, determining survival, breeding success, and recruitment. Historically penguins were initially marked with leg bands that were found to be impractical, difficult to deploy, hard to read, prone to being lost and causing injuries. They were replaced with aluminium flipper bands that were found to cause unacceptable injuries and even death.

Stainless steel flipper bands have now been used since the 1960s and have advantages such as easy identification at a distance and of dead penguins and are relatively cheap. However, these bands were also shown to have significant disadvantages such as reduced survival (8 studies), increased energy expenditure at sea (7 studies), reduced breeding success (3 studies), direct injuries (5 studies), a requirement for ongoing maintenance (3 studies), and increasing stress and disturbance (2 studies). No effect on population parameters was reported in 11 studies. Annual loss rate of flipper bands was reported to be between 0% and 22% in the first year after banding, generally lower thereafter.

An alternative to flipper bands is microchips which are inserted under the skin with a one-use sterile needle after the disinfection of the insertion site and using surgical glue to seal the wound to prevent tag loss and infection. Advantages of microchips include higher survival and recruitment rates and breeding success compared to flipper banded penguins, no drag causing increased energy expenditure at sea, lower disturbance at the nest (particularly for penguin species nesting in burrows or dense vegetation) and in colonies (where automatic readers are deployed to monitor arrivals and departures), and generally failure rates are low, although tag loss can be as high as 5% in the first year after marking, generally lower thereafter. Disadvantages of microchips include no external identification mark of a microchipped penguin, initial increase in stress during the insertion procedure, and the associated cost of the microchips itself and the equipment to read it (wands and antennae).

Web tags applied to the webbing of penguin feet are not widely used and are not suitable as a primary marker for penguins as the bird has to be handled to read the tag. Web tags cause a small tear in the webbing when they are lost. They do not create drag as they are in the folds of the web, no infections have been reported and they are cheap. Up to 6% loss rate (over 13 years) has been reported but web tags can be easily replaced, and no information is lost if the penguin has another marker (either flipper band or microchip).

Overall, the disadvantages of flipper bands outweigh their advantages particularly when considering that flipper bands were found to impact the estimation of population parameters they are meant to measure. There are also ethical and moral considerations as a method of marking that increases mortality and decreases breeding success is not in the best interest of individual penguins or populations, especially if the species is endangered.

Weighing up the relative merits of the different methods, it is recommended that all flipper banding of penguins in New Zealand should stop and the primary form of penguin marking, and identification should be microchips. All flipper bands on live birds throughout New Zealand should be replaced with microchips using web tags as a secondary marker to assess microchip loss and prevent the loss of information of individuals that have lost their microchip.

Contents

1 Introduction

Identifying individuals is required to enumerate a population, record breeding success, survival, and recruitment (Hindell et al. 1996, Gauthier-Clerc et al. 2004, Agnew et al. 2016, Boersma and Rebstock 2010). Unique marking of individuals generates data for mark and recapture studies enhancing the understanding of population ecology of the species, but the marking technique must not affect the animal's growth, behaviour, survival, or reproductive success (Carver et al. 1999, Klages and Spencer 1996, Hindell et al. 1996). It also must be retained throughout the animal's life and remain legible at recovery, otherwise the loss of the mark contributes to a negative bias in survival estimates (Carver et al. 1999). With the loss of a marker, there is a loss of data as the penguin will "disappear" from the marked population and will be presumed to have died even though it is still alive (Williams 1995, page 45), underestimating survival (Dann et al. 2014). Therefore, the probability of tag loss should be considered and minimised because tag loss can significantly affect the result of a study (Bonter and Bridge 2011).

I have summarised the history of penguin marking and listed the advantages and disadvantages of currently used marking methods (i.e., stainless-steel flipper bands, microchips, and web tags) with examples. In particular, this report examines the loss rate of each mark type and concludes with a recommendation for future marking of penguins in Aotearoa New Zealand.

2 History

2.1 Leg bands

The first penguins banded were Gentoo (*Pygoscelis papua*) and Adelie (*Pygoscelis adeliae*) penguins marked with a green celluloid band on their tarsi in the austral summer 1908/09 on islands of Palmer Peninsula, Antarctica by L. Gain (in Austin 1957).

Richdale (1951) further developed penguin marking by trialling various designs of leg bands for Yellow-eyed penguins (*Megadyptes antipodes*). While he acknowledged that injuries occurred, he did not enumerate the extent and frequencies of the damage but was primarily focused on legibility and durability of his various designs. He considered the most suitable band was made from strip aluminium 125 x 10 mm (Appendix 1), placed on the tarsus bone in the foot (Fig 1). Sladen and Tickell (1958) reported that no Pygoscelid (Adelie, Gentoo, and Chinstrap *P. antarctica*) penguins were banded successfully on the tarsus and birds sustained injuries.

Richdale (1951) also fitted aluminium bands on the tarsus of little penguins (*Eudyptula minor*) for one season but abandoned his efforts because the penguins were too small. In addition, he fitted yellow-eyed penguin tarsus bands on three Erect-crested penguins (*Eudyptes sclateri*) with one penguin surviving with the band for six years (Richdale 1951).

In the 1940s Sladen (1952) used the same bands as Richdale around the tarsus but found that they caused injuries to Adelie, Antarctic, and Gentoo penguins, were difficult to see and the numbers abraded rapidly on the rocks. He found leg rings (just above the tarsus) performed better and did not cause injuries. However, they were nearly always hidden by feathers, the penguin therefore had to be caught to determine a ring was present and to then read it if it was. Leg bands used on African penguins (*Spheniscus demersus*) were deemed inappropriate as the penguins lost them (Jarvis 1970).

Figure 1: Arrows indicating the tarsus on a Yellow-eyed penguin (photo H. Ratz)

2.2 Flipper bands

These were deemed a more appropriate marking for penguins and replaced tarsus and leg bands because banded penguins could be identified at a distance with binoculars (e.g., Sladen 1952) and thus reducing disturbance and stress.

2.2.1 Aluminium bands

Sladen (1952) fitted metal numbered flipper bands with clips bent flush with the rest of the band that lay on the inside of the flipper of Gentoo penguins on the Falkland Islands in December 1949 and the band number could be read with binoculars. The rings showed no sign of wear and only rubbed the short feathers at one place on the thin anterior edge of the flipper (Sladen 1952). The metal should fit the shape of the flipper fairly loosely and kinks were to be avoided otherwise damage will be done to the flipper during the moult when it almost doubles its thickness (Sladen 1952). If the band is too small, it can affect muscle and tendons that pass close to the posterior bend of the ring; and if they are too large, they may slip off or involve the flipper joints (Sladen 1952).

A different type of band with safety fasteners that flatten to form a projection anterior or posterior to the flipper and fit the flipper closer to the humeral articulation (the narrow part of the flipper close to the body) was used extensively on Ardley Island (South Shetland Island) starting in 1979 (Sallaberry and Valencia 1985). These were found to have caused wounds in 65% of penguins (of 603 Adelie, Gentoo, and Chinstrap penguins) after only two seasons, and in 1983 severe wounds caused by flipper bands were found in the thorax area of 15 penguins where complete erosion of feathers, skin and in some instances the musculature leaving the ribs visible had occurred (Sallaberry and Valencia 1985, see Appendix 2).

Sladen and Penney (1960) further refined the aluminium flipper band to its final design (Appendix 3, Figure 1C) with no overlap or locking device. They reported no injuries the following year (after the birds had moulted and overwintered at sea) but found some wear of the feathers along the anterior border of the flipper which did not harm the bird (Sladen and Penney 1960). In another study of Adelie penguin, freshly banded adults had 28% lower survival rate in the first year attributed to flipper injuries caused by swelling during the moult (Ainley et al. 1983). Aluminium bands were also found to be of inferior quality in later studies, causing injury and even death, and had a high annual loss rate of 5-22% (Ainley and DeMaster 1980, Boersma and Rebstock 2010, Weimerskirch et al. 1992, Clarke and Kerry 1994). Aluminium flipper bands have mostly been discontinued and either been replaced with stain-less steel bands, microchips, or web tags.

2.2.2 Stainless steel bands

Flipper tags have been traditionally used to mark penguins for long-term studies (Clarke and Kerry 1998). Bands made of stainless steel have been used since the 1968 for Little penguins on Phillip Island (Australia) that had no overlap, clips or fasteners (Dann et al. 2014, see also Appendix 4) and since the 1980s for Magellanic penguins (*Spheniscus magellanicus*) with a small overlap (Boersma and Rebstock 2010). This overlap of the ends allows each band to be individually fitted to the penguin (Appendix 5). Hundreds of thousands of flippers bands have since been deployed globally on all penguin species (Dann et al. 2014).

In New Zealand, flipper bands of unknown composition have been used starting in 1972 (Department of Conservation database) to mark Yellow-eyed penguins but stainless-steel bands were used since 1980 for marking Yellow-eyed penguins (Darby and Seddon 1990), but they have been mostly replaced with microchips in recent years. Flipper bands have been used for Little penguins in Oamaru since 1985 (Agnew et al. 2015, Agnew et al. 2016) and between 2002 and 2010 at Penguin Place (Otago Peninsula) but were replaced with microchips from 2011 (H. Ratz unpubl. data). Little penguins were also fitted with flipper bands on Matiu/Somes Island (Cotter 2012).

2.3 Web marking

In addition to various leg bands, Richdale (1951) also developed a footmarking system whereby he punctured the web with a leather punch in three precise places with a unique combination. He marked 1103 individuals in this way up the end of the 1948/49 breeding season. He noted that birds suffered foot injuries, holes high up the web sometimes grew over and those on the edge of the webs sometimes split. To identify the bird, it had to be caught, an unavoidable disadvantage (Richdale 1951). This method was also used on penguin chicks in Antarctica to determine chick survival (Sladen and Tickell 1958) and to assess band loss (Ainley and deMaster 1980).

Web tags (Appendix 5) were used for Magellanic penguins since 1994 to assess initially flipper band loss (Boersma and Rebstock 2010) and later microchip loss (Boersma and Rebstock 2009). Web tags are self-piercing, numbered, small animal ear tags (2 × 10 mm). Due to their small size and placement, it is assumed that web tags caused little or no drag. When a penguin is swimming, its feet trail behind with the tag in the folds of the web. Web tags cannot be read from a distance and penguins have to be captured to read the tags. To assess microchip loss, web tags were deployed in little penguins on the Otago Peninsula at Penguin Place (2011-2013) (Ratz unpubl. data) and at Takihururu/Pilots Beach (Ratz 2019).

2.4 Microchip, Passive Integrated Transponders (PIT), Radio Frequency Identification (RFID)

The names of these tags are interchangeable and will be referred to as microchips for the remainder of this report. They have been used in amphibians and reptiles (e.g., Camper and Dixon 1988), mammals (e.g., Thomas et al. 1987) and birds (e.g., Jackson and Bunger 1993) since the 1980s.

In 1991, the first microchips were injected under the skin (unspecified location) of King penguins (*Aptenodytes patagonicus*) but no loss rate or challenges were reported (Le Maho et al. 1993). Kerry et al. (1993) microchipped Adelie penguins in Antarctica injecting them posterior to anterior in the neck area and found several tags had worked their way out from the wound before it healed. Chicks that had died of other causes showed no abnormalities around the microchip (Kerry et al. 1993). Significant losses of microchips were reported by Clarke and Knowles (1998) as well the potential for migration of the microchip and possible infection. They adjusted their methodologies by injecting the microchip anterior to posterior in the neck, disinfecting the site prior to injection and applying glue to seal the wound. Microchip loss subsequently dropped from 30% to 1%, migration ceased, and no infections were recorded (Clarke and Knowles 1998).

2.4.1 Insertion site

Microchips were injected just under the skin in the lower left tarsometatarsus of Magellanic penguins because it is close to the ground (facilitating reading by the antennae of the automatic microchip reader) (Boersma and Rebstock 2009). Microchips inserted in the back and face can break because these locations can receive frequent pecks and bites as well as hits from flippers when penguin fight (Boersma and Rebstock 2009). A King penguin study on

Possession Island from 1998 also injected microchips under the skin of the leg to facilitate reading by an automatic reader (Gauthier-Clerc et al. 2004, Gendner et al. 2005). Olson and Brodin (1997) have inserted microchips in the back and between the tail and leg on the dorsal side of King penguins, and Clarke and Kerry (1998) inserted microchips halfway down the back of Adelie penguins. Royal penguins (*Eudyptes schlegeli*) had microchips inserted in the front near the sternum (Hindell et al. 1996).

Little penguins have been microchipped in the back of the neck in Australia (Dann et al. 2014, in the Marlborough Sounds (Renner and Davis 2000), on Matiu/Somes Island from 2007 (Cotter 2012), recently at Oamaru (Agnew and Houston 2020), at Mount Maunganui since 2011 (Sievwright 2014) on the Otago Peninsula at Penguin Place since 2011 (H. Ratz unpubl. data) and Pilots Beach/Takiharuru (2016-2021) (H. Ratz unpubl. data) as well as in various other locations throughout New Zealand in recent years. Yellow-eyed penguins and Fiordland penguins are marked with microchips in the back of the neck like Little penguins (pers. obs.).

2.4.2 Microchip size

Different microchip sizes are used for penguins depending on the species' size and method of scanning (handheld readers, automatic antennae) used. The largest microchips (30mm long, 3mm in diameter, weighing 0.8g, detection distance 700mm) have been used for Adelie penguins (Clarke and Kerry 1994) and King penguins (Le Maho et al. 1993). A medium sized microchip (23mm long, 4mm in diameter, weighing 0.6g, detection distance up to 400mm) have been used for Little penguins (Renner and Davis 2000), Yellow-eyed penguins and Fiordland penguins (*Eudyptes pachyrhynchus*) (H. Ratz, unpubl. data). A smaller microchip (11mm long, 2mm in diameter, detection distance up to 50mm) have been used for Little penguins in Australia (Dann et al. 2014) and in New Zealand (Ratz 2019). Little penguins in Oamaru are inserted with 8mm microchips (P. Agnew pers. comm.)

2.5 Other methods of identifying penguins

Some penguin species have black feathers on their white fronts that can be used for identification of individuals without external (flipper bands) or costly microchips. For example, African penguins each have a unique pattern that have been used with a computer recognition system to consistently identify individuals for population parameter studies (Sherley et al. 2010 – see also Appendix 6 for examples). However, not all penguins and not all penguin species have these black feathers on their white fronts, making this recognition system only suitable for some species.

3 Current marking methods of penguins: advantages, disadvantages, and loss rate

This section examines current marking methods for penguins. Aluminium bands and leg bands are no longer used in New Zealand. The advantages, disadvantages, and loss rate of stainless-steel flipper bands, microchips, and web tags are compared from studies published in the scientific literature for penguin species worldwide.

3.1 Flipper bands

Marking penguins with a stainless-steel band around the proximal end of the flipper has now been used for many decades on most penguin species around the world on hundreds of thousands of penguins (Dann et al. 2014).

3.1.1 Advantages of flipper bands

a) This external marker allows relatively easy identification of banded penguins with binoculars even at a distance (e.g., Le Maho et al. 1993, Weimerskirch et al 1992).
b) Flipper banded dead penguins are more likely to be recovered by the public (and sent to an address provided on the band) compared to microchipped ones as these require expensive readers (Dann et al. 2014, Le Maho et al. 2011, Renner and Davis 2000, Sievwright 2014) although small hand-held readers have become affordable.
c) Relatively cheap (Le Maho et al. 2011).

3.1.2 Disadvantages of flipper bands

3.1.2.1. Reduced survival

a) Little penguin adults (Australia): in the first year after marking, banded individuals had 6% lower annual survival compared to microchipped individuals (75% for banded, 81% for microchipped individuals). In subsequent years, survival for banded adults was 87% and 91% for microchipped adults (Dann et al. 2014).
b) Little penguin (Australia): expected future lifetime is 6.3 years for banded individuals and 9.9 years for unbanded individuals, based on average annual survival probabilities (Dann et al. 2014).
c) Adelie penguin adults: survival was 11-13% lower for banded individuals in some years compared to microchipped individuals during 2000-2003 seasons (Dugger et al. 2006).
d) Adelie penguin adults: survival of banded adults (63-90%) was lower than microchipped adults (78-91%) (Clarke and Kerry 1998).
e) King penguin chick: survival of banded individuals was about half that of microchipped chicks 2-3 years after marking (Gauthier-Clerc et al. 2004).

f) King penguin adults: single banded individuals had a 21% lower survival compared with microchipped adults in the first year after banding and a 7% lower survival in the second year after banding (Froget et al. 1998).
g) King penguin adults: a larger proportion of unbanded individuals returned in four out of five years compared to banded individuals (Gauthier-Clerc et al. 2004).
h) King penguin adults: Banded individuals had a 16% lower survival than unbanded individuals, with a survival rate over 4.5 years of 62% for unbanded and 32% for banded individuals, and an annual survival rate of 90% and 78% respectively (Saraux et al. 2011).

<u>3.1.2.2. Increased energy expenditure at sea</u>

a) Adelie penguin adults: Banded individuals foraged 8% (or 3.5 hours) longer than microchipped individuals (Dugger et al. 2006).
b) Little penguin adults (Australia): Banding had an immediate negative effect on the diving performance one day after banding (Fallow et al. 2009).
c) Little penguins (Australia): feather wear on the banded flipper appears to indicate a change in hydrodynamic properties that reduces the surface area of the flipper and reduces the amount of thrust produced by each stroke cycle, but more studies are required (Fallow et al. 2009, see also Appendix 7).
d) Adelie penguin adults: Banded individuals expended 24% more energy in a swimming tank compared to unbanded individuals due to drag and disturbance of wing flow characteristics, physical impairment of the wing and a rudder effect of the band, which will not change over time. (Culik et al. 1993). This may result in overall reduction of breeding success especially in years of low food availability (Culik et al. 1993).
e) Adelie penguin adults: 24% increase in swim cost leads to an effective decrease in foraging efficiency by doubling the cost (Jackson and Wilson 2002).
f) Magellanic penguin adults (males): mean trip duration was 8 hours longer for banded individuals compared to web tagged ones (not significant due to high variability) (Boersma and Rebstock 2009).
g) King penguin adults: foraging trips were significant longer for banded compared to unbanded individuals (Saraux et al. 2011).

<u>3.1.2.3. Reduced breeding success</u>

a) King penguin adults: banded individuals arrived later in the colony, had a lower breeding probability, reduced mate selection and lower chick production (Gauthier-Clerc et al. 2004, Froget et al. 1998, Saraux et al. 2011).
b) King penguin adults: banded individuals laid eggs later, produced 39% fewer chicks than unbanded individuals (Saraux et al. 2011).

3.1.2.4. Injury

a) Bands can cause feather wear resulting in bare skin, broken skin, or open wounds (Peterson et al. 2005).
b) Little penguins: the flipper with the band was observed to be swollen about twice as much as the flipper without the band during the moult (pers. obs.) although no subsequent mortality was observed.
c) Adelie penguins: injuries occurred due to the opening of the band and penetrating the radio-carpal joint (Appendix 8) (Clarke and Kerry 1998).
d) Magellanic penguins: 32% of resighted penguins had injuries or feather damage caused by bands (Bhering et al. 2002, Appendix 9).
e) Flipper bands can potentially entangle penguins in vegetation and cause injury or death (Peterson et al. 2005, pers. obs. for Little and Yellow-eyed penguins).

3.1.2.5. Ongoing maintenance is required

a) Adelie penguins (Clarke and Kerry 1994)
b) Yellow-eyed penguins (McFarlane 2013)
c) King penguins (Olson 1997)

3.1.2.6. Disturbance

a) Little penguins (Australia): studies of nest attendance in colonies of burrow-nesting penguins necessitate the removal of birds from the burrow to read flipper bands. This method causes undesirable disturbance to the individuals and to the colony as a whole (Chiaradia 1996).
b) Little penguins (NZ), Yellow-eyed penguins: if the banded side of the penguin faces away the penguin has to be touched and manipulated to be able to read the band number, thus increasing stress and time at the nest (pers. obs.).

3.1.3 Neutral effect of flipper bands

a) Royal penguin adults: banded individuals had no different survival rate, reproductive success and chick weights compared with microchipped individuals for one season (Hindell et al 1996).
b) African penguin adults: banded individuals had no different breeding success compared with unbanded individuals for one season (Hampton et al. 2009).
c) Little penguin adults (Oamaru): Inconclusive results for the difference of survival rates of banded individuals compared to microchipped ones and further research is required (Agnew et al. 2016).
d) Magellanic penguin adults: the survival of banded males was not impacted, but double banded females had a reduced survival although egg size and breeding success were not impacted negatively (Boersma and Rebstock 2010).
e) Magellanic penguins: direct damage caused by bands is rare (Boersma and Rebstock 2009).

f) Magellanic penguins: Mean trip duration was no different between banded and web tagged females during chick rearing (Boersma and Rebstock 2009).
g) King penguins: no flipper injuries were observed (Froget et al. 1998).
h) Adelie adults: there was no difference in food loads brought to chicks between banded and unbanded individuals (Dugger et al. 2006).
i) African penguins: No case of definite harm has been observed among thousands of birds recaptured (Cooper and Mordant 1981).
j) Snares penguins (*Eudyptes robustus*): no show of wear after nine years (Cooper and Mordant 1981).
k) Yellow-eyed penguins: double banding did not influence breeding success in the season the extra band was applied, and it did not affect lifetime reproductive success (the effect of single bands was not investigated) (Stein et al. 2017).

3.1.4 Loss rate of flipper bands

The rate of band loss can only be determined if the penguin is also marked in some other way (e.g., microchip, web tag, web punching or double flipper banding).

a) Little penguins (Australia): 0.7% of adults in the first year, 0.2% in subsequent years, 2nd marker microchips (Dann et al. 2014).
b) King penguins: 22% loss during the first year and 4.5% during the second year, 2nd marker leg bands (Weimerskirch et al. 1992).
c) Royal penguins: 0% band loss after winter, 2nd marker microchips (Hindell et al. 1996)
d) King penguins: 0% loss four years post marking, 2nd marker microchips (Olson 1997, Olsen and Brodin 1997)
e) King penguins: 2% band loss, 2nd marker flipper band (double-banding) (Froget et al. 1998)
f) Little penguins (Australia): 0.4% band annual loss, 2nd marker microchips (Sidhu et al. 2007)
g) Adelie penguin adults: no loss after one year, 2nd marker microchips; 1% loss after two to three years (Clarke and Kerry 1994)
h) Magellanic penguin adults: no loss after 13 years (Boersma and Rebstock 2010).

3.1.5 Double banding with flipper bands

In some studies, the flipper band loss is assessed by double-banding the penguins (i.e., a flipper band on both flippers). For example, Trivelpiece and Trivelpiece (1994) compared the return rates of single and double banded Adelie, Gentoo, and Chinstrap penguins, and found a lower return rate for double banded penguins in all three species: Adelie penguin single banded (39%) vs double banded (31%); Gentoo penguin single banded (56%) vs double banded (31%); Chinstrap penguins single banded (44%) vs double banded (32%). Only 0.5% of double banded Chinstrap penguin chicks returned compared to 11% of single banded chicks.

The return rate of double banded King penguins was only 45% compared to single banded birds (76%) and very low compared to unbanded birds (97%) (Froget et al 1998). The increase in energy expenditure might be greater for double banded birds compared to single banded and the impact on return rate mainly occurs during the winter (Froget et al. 1998).

Double banded Magellanic penguin females had an 8% lower survival compared to double banded males and (male and female) penguins with web tags suggesting that the impact of double banding is likely to be higher than single banding, but it is not known by how much (Boersma and Rebstock 2010).

Considering the impacts of flipper banding identified above, and the availability of microchips as a second marker to assess loss, double banding of penguins extracts too high a cost on the penguins and should long longer be considered a valid method to determine flipper band loss.

3.1.6 Additional comments on flipper bands

In some circumstances, penguins may open a flipper band with their bill which contributes to band loss (Clarke and Kerry 1998). Flipper bands have to be fitted properly (Boersma and Rebstock 2010) and require regular maintenance (McFarlane 2013). Every major life-history trait can be affected calling into question the banding schemes still going on and the quality of the data collected to measure these traits accurately (Saraux et al. 2011). Steps should be taken to minimise the impact of marking by considering alternative procedures to flipper bands (e.g., implanted tags) (Clarke and Kerry 1994). Higher mortality of banded individuals could be considered a weeding out of lower quality individuals from the population (Wilson 2011) as birds are not ultimately able to adapt to their band (Gauthier-Clerc et al. 2004).

In 2016, the National Center for Wild Birds research and conservation banned the use of flipper bands to mark penguins in Brazil (Bhering et al. 2022) and Jackson and Wilson (2002) recommend that flipper bands should no longer be a method of choice in penguin studies. In Mount Maunganui (New Zealand) any banded Little penguin encountered from 2011 had its band removed and replaced with a microchip (Siewright 2014).

3.2 Microchips

Penguins are implanted with passive integrated transponder (PIT) tags supplied in sterile individually packed needles. These are injected under the skin and, in some studies, sealed with surgical glue to prevent loss of the PIT tag and infection even if it increases handling time (e.g., Dann et al. 2014). The injection site is disinfected prior to insertion (e.g., Clarke and Kerry 1998).

3.2.1 Advantages of microchips

a) Little penguins (Australia): Failure rate is unlikely; no internal damage or migration of the microchips was found in penguins killed by foxes (Dann et al. 2014)
b) Survival and recruitment: generally higher for microchipped penguins compared to banded penguins (see above for examples) and up to 25% higher return rates for microchipped Adelie penguins (Clarke and Kerry 1998).

c) No impact on energy expenditure at sea or foraging efficiency as they are internal and don't create drag (Gauthier-Clerc et al. 2004).
d) Breeding success: higher for microchipped penguins compared to banded penguins in some studies (see above for examples).
e) No injury rates to reduce survival or foraging efficiency (Dann et al. 2014, Le Maho et al. 2011).
f) Adelie penguin adults: No problems with tag failure, migration or infection (Dugger et al. 2006, Kerry and Clarke 1998, Kerry et al. 1993).
g) Automatic weigh bridges and readers greatly reduce investigator disturbance while collecting high quality and accurate data even with gaps due to equipment failure (Le Maho et al. 1993, Gauthier-Clerc et al. 2004, Clarke and Kerry 1994).
h) Nest checks of burrow nesting penguins is done with minimal disturbance (Chiaradia 1996, Renner and Davis 2000, Sievwright 2014) even if the penguin is not visible.
i) Fast identification of penguins without handling during foreshore surveys even in low light conditions (McLuskie pers. comm.)

3.2.2 Disadvantages of microchips

a) Microchipped penguins cannot be visually identified (Bhering et al. 2022, Gauthier-Clerc et al. 2004).
b) It is not possible for members of the public who may find a dead, microchipped Little penguins to identify it and report it (Sidhu et al. 2012). This precludes the gathering of information by the general public from more widespread areas (Dann et al. 2014) although if a dead bird is returned, it can then be identified by a person with a reader (Sievwright 2014).
c) Initial stress level in Little penguins was higher during microchipping compared to banding procedure but long-term stress effect of either method still to be investigated (Lowe 2009).
d) Microchips and hand-head readers are more expensive than flipper bands and binoculars (Dann et al. 2014, Gauthier-Clerc et al. 2004, Le Maho et al. 2011, Renner and Davis 2000), although the cost of small hand-held readers has come down in recent years.
e) Automatic identification set ups are expensive and require maintenance (Le Maho et al. 2011).
f) Reading distance of a microchip increases with its size (Clarke and Kerry 1998), making small microchips unreadable if they are too far away from the automatic readers' antennae, and increase disturbance by approaching penguins close enough with a hand-held reader (Gauthier-Clerc et al. 2004).
g) Automatic readers require a bottle-neck access path to guide the penguins close to it for the tag to be read (Gauthier-Clerc et al. 2004) which is not possible for some species.

3.2.3 Neutral effect of microchips

a) Survival rates: no difference between microchipped and banded penguins (Royal penguins (Hindell et al. 1996), Little penguins (NZ) (Agnew et al. 2016), male Magellanic penguins (Boersma and Rebstock 2010)
b) Breeding success: no difference between microchipped and banded penguins (African penguins (Hampton et al. 2009)).
c) There was no difference in food load brought to chicks between banded and unbanded individuals (Adelie penguins (Dugger et al. 2006)).
d) Little penguins killed by foxes were examined and no damage of the microchip or migration was found more than one year post marking (Dann et al. 2014).

3.2.4 Loss rate of microchips

The initial loss rate of 30% during the first two years in Adelie penguins was a result of the microchip being inserted posterior to anterior around the neck. The location was changed to anterior to posterior resulting in 3-5% loss rate and sealing the wound with glue reduced loss rate further to 1% loss rate (Clarke and Kerry 1998), a method now widely used. Microchip loss occurs when the microchip exits the wound at the injection site before it heals (e.g., Gibbons and Andrews 2004, Kerry et al. 1993) or the microchip can't be scanned because it malfunctioned or migrated (Dann et al 2014).

a) Little penguins (Australia): 5% loss in the first year, 1% loss thereafter; most microchip loss occurs soon after injection, 2nd marker flipper bands (Dann et al. 2014).
b) Royal penguins: 1.6% after one winter, 2nd marker flipper bands (Hindell et al. 1996).
c) Adelie penguin adults: 1% loss after a fortnight prior to healing, and 0.5% after nine months, 2nd marker flipper bands (Clarke and Kerry 1994).
d) King penguins: 0% loss, 2nd marker flipper bands (Olson 1997, Olsen and Brodin 1997).
e) Little penguins (Australia): 4% loss in the first year, 1% loss in subsequent years, 2nd marker flipper band (Sidhu et al. 2011).
f) Adelie penguins: no problems with failure, migration, or infection (Dugger et al. 2006)

3.2.5 Additional comments on microchips

Inserting microchips requires certification in New Zealand by the Department of Conservation, involving experience with a minimum of 30 penguins fitted with microchips under supervision of a qualified person. Inserting microchips involves best practice and expertise is imperative (Dann et al. 2014) but the benefits of marking penguins with microchips outweigh the associated costs (Siewright 2014). An initial report of a biofilm around a microchip that may harbour pathogenic organism has been resolved by using sterile needle and sealing the wound with surgical glue (Clarke and Kerry 1998, Gibbons and Andrews 2004), a common practice for most species (e.g., Dann et al. 2014).

3.3 Web tags

Web tags were self-piercing, numbered, small animal tear tags (2x10mm) applied to the outer edge of the webbing between toes (Boersma and Rebstock 2009, Ratz 2019) (Appendix 5). It is not a widely used marking method for penguins.

3.3.1 Advantages of web tags

a) Magellanic penguins: web tags are assumed not to create drag because its feet trail behind with the tag in the folds of the web (Boersma and Rebstock 2010).
b) Magellanic penguins: no infections or swelling due to web tags were found over 26 years (Boersma and Rebstock 2009, 2010).
c) Little penguins: no infections were observed at Penguin Place or Pilots Beach/Takiharuru in New Zealand (pers. obs.).
d) Web tags are relatively cheap and cause no injuries (Le Maho et al. 2011).

3.3.2 Disadvantages of web tags

a) Magellanic penguins: individuals had to be pulled from their nest by hand to read the web tag (Boersma and Rebstock 2010, Le Maho et al. 2011).
b) Magellanic penguins: when lost the web tag leaves behind a small tear in the webbing (Boersma and Rebstock 2010).

3.3.3 Loss rate of web tags

c) Magellanic penguins: 5.6% of adults lost one of two web tags over six years (Boersma and Rebstock 2010).
d) Magellanic penguins: 0% loss over 16 months (Boersma and Rebstock 2009).

3.3.4 Additional comments on web tags

Web tags are ideal as a second marker for microchipped penguins without the disadvantages of flipper bands (Ratz 2019) but should not be used as the primary marker for penguins because they are difficult to read, and the penguin has to be handled to read the number. Double marked penguins with microchips and web tags rarely loose both marks at the same time (H. Ratz unpubl. data) and they can be replaced without the loss of information about the individual.

4 Conclusions

Regardless of one's preference of marking methods, there is evidence that any method has advantages and disadvantages. It is important to consider the important question of ethics and moral implications as well as the effects of marking in the broader issue of bias in scientific studies. The potential impact of marking on survival and breeding success is clearly not in the interest of penguin conservation particularly for endangered species. Life-history traits of penguins obtained through methods that impact the parameters they are meant to measure need to be re-considered. Any long-term study needs to be carefully planned to minimise not just the impact of the marking on the penguin, its survival and breeding success, but also how tag loss is measured and accounted for (by double-tagging). A precautionary approach based on the data from all penguin species is recommended before a marking method is approved.

5 Recommendations

1. Flipper banding of all New Zealand penguin species is no longer implemented.
2. All flipper bands currently used for penguins are replaced with microchips.
3. A second marker such as web tags is used to prevent loss of identification of individuals and assess microchip loss.
4. All records of marked penguins (flipper banded, microchipped and web tagged) are reported to FALCON administered by DoC, including removal of bands that have been replaced by microchips.

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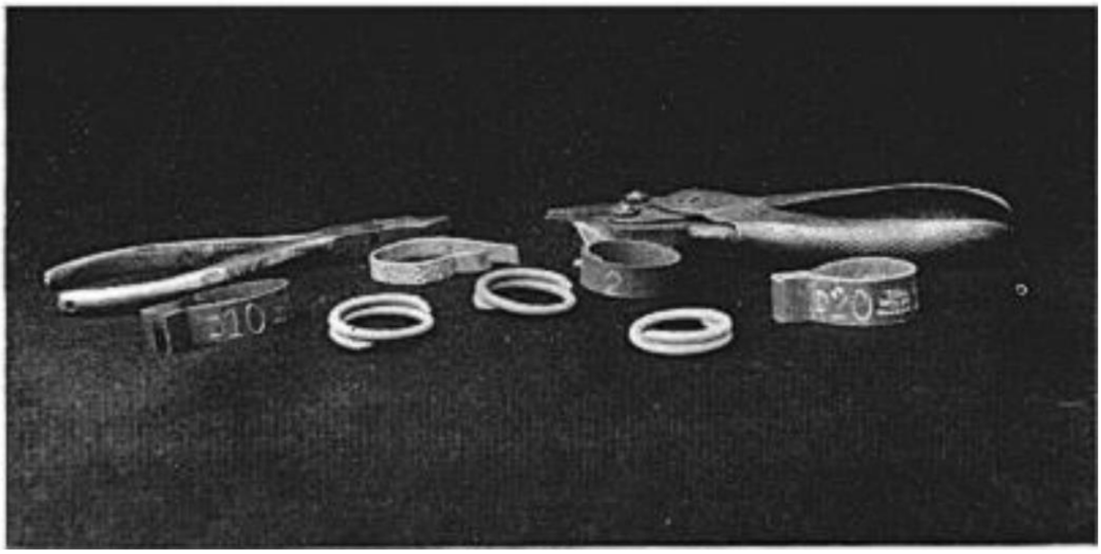
Appendix 1

Richdale (1951) figure 1 on page 48



The tools of banding. At back, two types of pliers; in front, three coil bands; at each end, two aluminium bands like those in present use; behind coil bands, narrow aluminium, band, and a celluloid band.

Appendix 2

Sallaberry and Valencia (1985) Figures 1 and 2 on pages 275 and 276

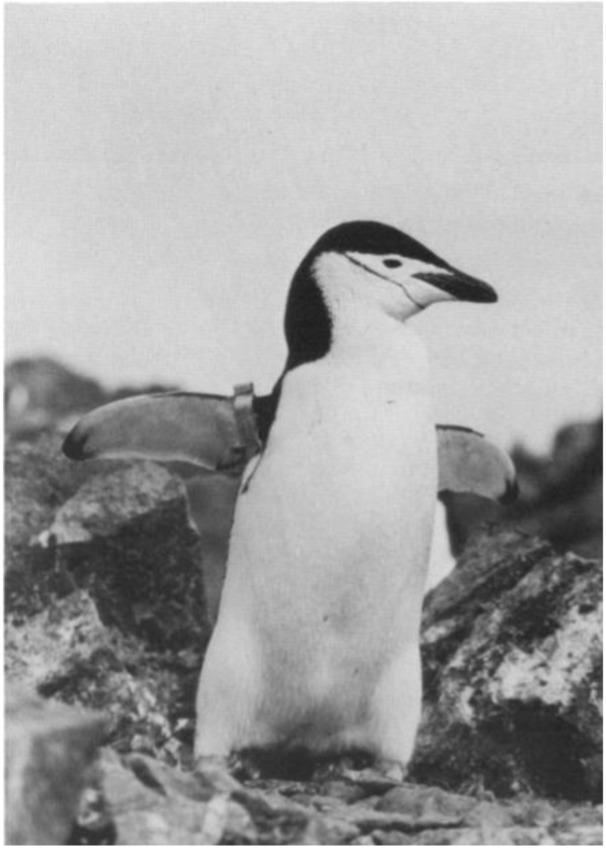


Figure 1: Chinstrap Penguin banded with an injurious flipper band, with safety fastener projecting anteriorly.

Figure 2: Wound on the left flank of a Chinstrap Penguin caused by friction from a safety fastener projecting caudally.

Appendix 3

Sladen and Penney (1960) Figure 1 on page 80

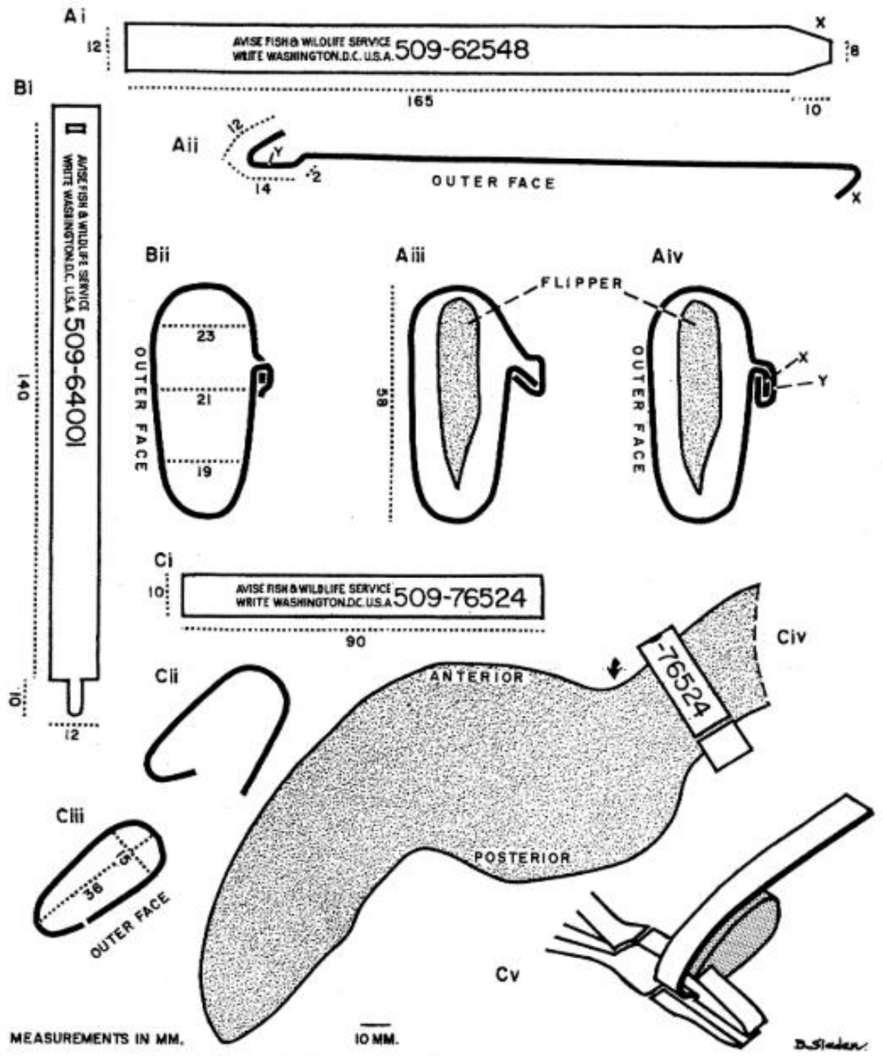


Figure 1. *USARP Penguin-flipper bands*

A 1958 design for Emperor Penguin. (i) first shaping. (ii) second shaping. (iii) shaped around flipper. (iv) final position.

B 1959 design for Emperor Penguin. (i) strip as supplied. (ii) final position around flipper.

C 1958 & 1959 designs for Adelie & Chinstrap Penguins. (i) the strip supplied in 1958, cut to correct length. (ii) the pre-shaped band supplied in 1959. (iii-iv) final position around flipper. Comment on the arrow is in text. (v) pliers for shaping strips. Shows strip partly shaped.

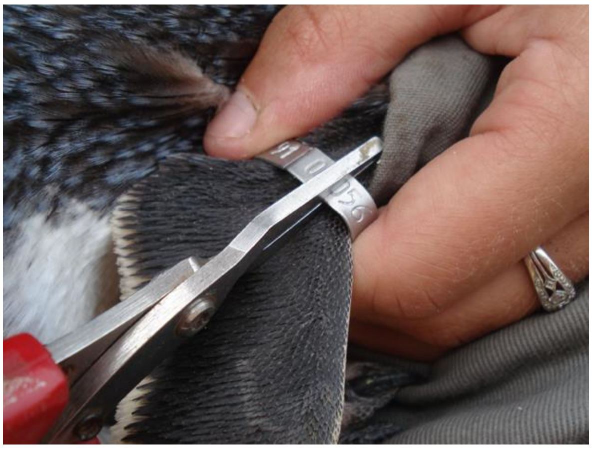
Appendix 4

Dann et al. (2014) supporting information in the online version

Fig S1. Photographs showing flipper banding of Little Penguins and its position on the flipper. Note: the bottom right photo shows feather wear on the flipper after the removal of the band.

ibi12122-sup-0001-figs1

ibi12122-sup-0002-figs1



ibi12122-sup-0003-figs1

ibi12122-sup-0004-figs1

Appendix 5

Boersma and Rebstock (2010) figure 1, page 410

Fig.1 Identifying tags used on Magellanic Penguins at Punta Tombo, Argentina.
(A) Flipper band on left flipper on an adult Magellanic Penguin.
(B) Web tag on left foot of a Magellanic Penguin chick.
(C) RFID tag (left), web tag (center), and flipper band (right). The web tag is open, prior to attachment. The pointed end pierces the webbing, goes through the hole in the opposite end, and fold over to lock. The flipper band is closed as it would be on a penguin. Note the tear-drop shape and overlapping end. A, B, and C are not to the same scale.

Appendix 6

Sherley et al. 2010 figure 2 on page 104, and figure 3 on page 105

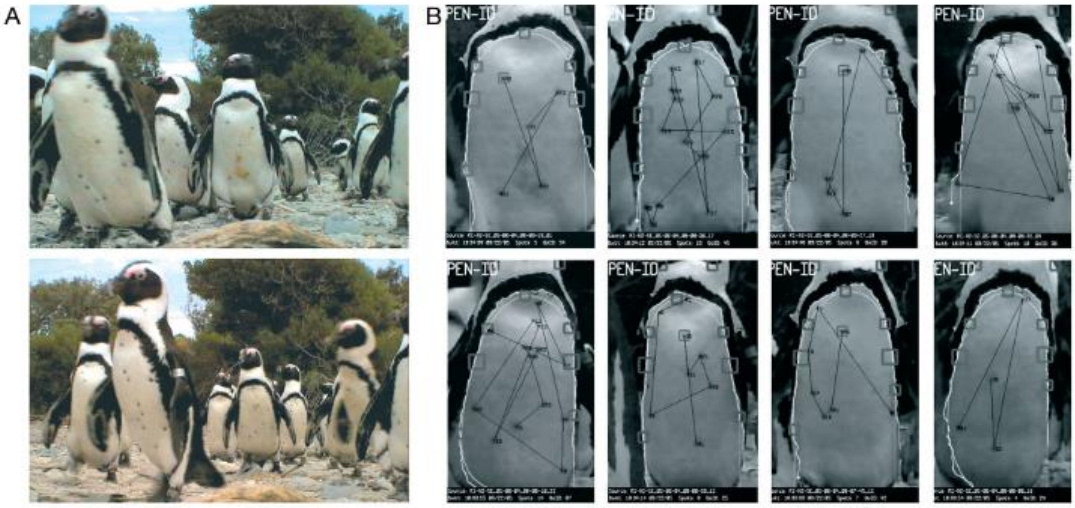


Figure 2: (A) representative frames of passing African penguins as captured by the field camera system; (B) sample identifications of chest patterns in the population database.

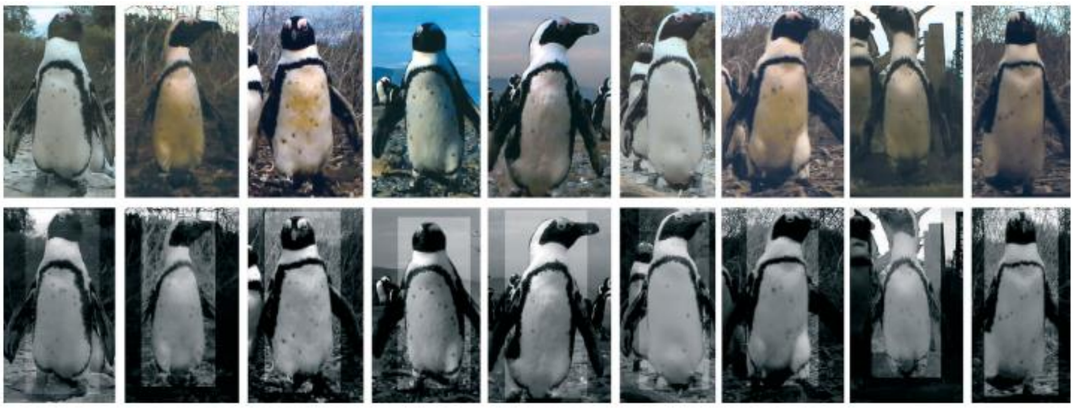
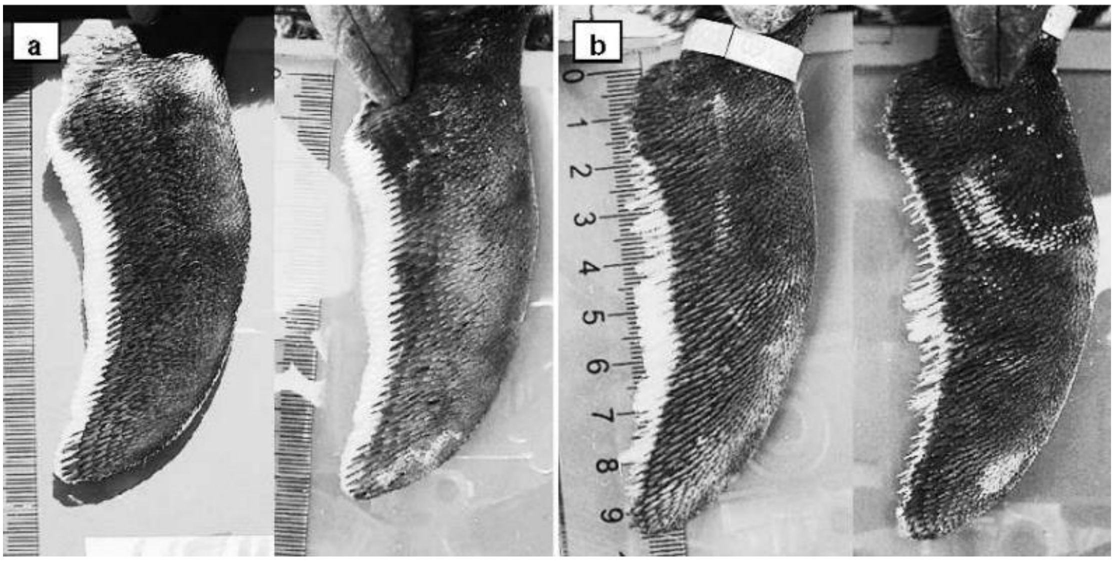


Fig. 3. Top: original penguin detection images stored by the African Penguin Recognition System (APRS); bottom: z-score lighting corrected images. Corrections can normalise for some lighting changes and should improve the ability to capture images in a field scenario.

Appendix 7

Fallow et al. 2009 Figure 1 on page 1352



Flipper wear of little penguins on Phillip Island, Australia. We measured the degree of wear of the white feathers of the trailing edge for (a) an unbanded and (b) a banded bird. Left and right photos in (a) and (b) were taken in October 2005 and January 2006 respectively.

Appendix 8

Injuries caused by flipper bands:

Clarke and Kerry (1998) Figure 1B on page 152

Injury due to a flipper band opening and penetrating the radio-carpal joint of an adult Adelie penguin (after 1 year of wear). The band was subsequently removed and, although the joint remained swollen for several months, the bird returned to the colony to breed in the following two seasons.

Boersma and Rebstock (2010) Figure 2 on page 199

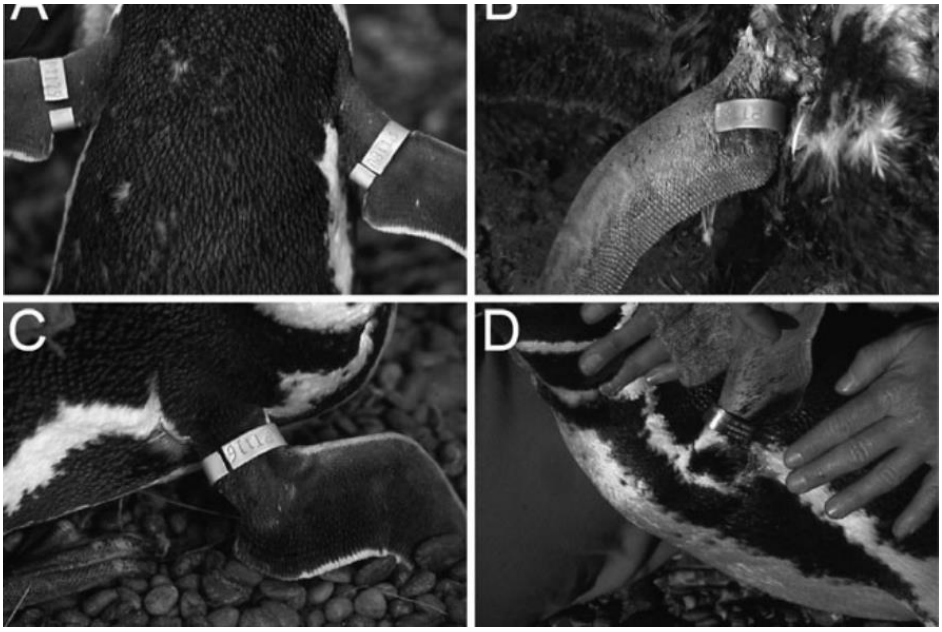


Fig. 2. Damage to feathers and flippers caused by double bands on Magellanic Penguins at Punta Tombo, Argentina. (A) Aluminium bands have worn notches in the leading and trailing edges of both flippers. The band on the left is open, and the band on the right is skewed (ends not aligned). (B) An aluminium band opened far enough to pierce the flipper. The penguin died because of the injury in February or March 1994. (C) An open Aluminium band cut a large notch

in the trailing edge of the flipper (between the white feathers close to the body and the elbow joint) and wore away body feathers under the flipper (visible to the left of the flipper base). (D) A stainless-steel band wore away body feathers behind the flipper.
best (A) Aluminium bands have worn notches in the leading and trailing edges of both flippers. The band on the left is open, and the band on the right is skewed (ends not aligned).
(B) An Aluminium band opened far enough to pierce the flipper. The penguin died because of the injury in February or March 1994.
(C) An open Aluminium band cuts a large notch in the tailing edge of the flipper (between the white feathers close to the body and the elbow joint) and wore away body feathers under the flipper (visible the left of the flipper base).
(D) A stainless-steel band wore away body feathers behind the flipper.