A burrowscope for examining petrel nests in burrows

P Lyver, S Hamilton, M McKenzie, I Dickson, M Dooher T Broad and H Moller
Department of Zoology
University of Otago
PO Box 56
Dunedin
New Zealand

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Abstract

This report describes the development and refinement of a burrowscope that is reliable and robust enough to withstand arduous field conditions crucial for obtaining accurate data on sooty shearwater *(Puffinus griseus)* burrow occupancy and breeding success. The burrowscope consists of a miniature camera and infra-red lights mounted on a three metre length of hose through which images are projected on to a screen at the surface. Movement of the camera-head was important to allow burrowscope penetration, adequate inspection of the burrows tunnels and side chambers, and to negotiate corners and obstacles. A hydraulic system for moving the camera-head was not as reliable as a cable system. Occupancy could not be determined for about a third of all burrows on Poutama Island where the deep peaty soils and abundant tree roots are associated with long and complex burrow structures. Ability to determine occupancy declines rapidly once burrows are longer than about 1.5 to 2 m, partly because the burrowscope cannot be manipulated around corners or obstacles once it has penetrated so far into the ground. Weather conditions and especially the temperament of different operators probably affect precision and reliability of the data. Standardisation of the burrowscope design and the way it is used in a study is important for consistency, but even so the burrowscope may be very inaccurate for comparisons between places, or even between different times at the same place. Research is needed to determine whether there are parameters of burrow structure and geometry that can be measured from above ground during burrowscope surveys to predict a "correction factor" to account for eggs or chicks missed by the burrowscope.

1. Introduction

Ascertaining nest presence and accurate identification of nest occupants is essential when studying the breeding biology of burrow- or cavity-nesting birds (Dyer & Hill 1991; Purcell 1997). For burrow-nesting birds, estimates of the number of breeding pairs are often based on indirect indicators, such as apparently "occupied" burrows. Such estimates are subject to error from a range of sources, and this error will be of unknown magnitude (Dyer & Hill 1991). Survey methodology using sound, smell and sign at burrow entrances (Warham & Wilson 1982), or probing with a stick or wire to determine burrow occupancy, have proved too inaccurate to reliably index population size or breeding success (Hamilton in press. a & b). The identification of burrow occupants and nest presence can be extremely difficult, especially for burrows more than two metres long (Hamilton in press. a & b). Therefore, studies may be restricted to atypically short burrows, ones that have collapsed or been excavated, or possibly to younger birds caught on the surface (Warham 1966; Dyer & Hill 1991). This restriction may severely limit a study of breeding biology, especially if burrows of different lengths are occupied by birds with different breeding experience or breeding success. It is imperative to have a method of determining burrow occupancy applicable to every burrow in any colony.

In recent years, optical equipment has been modified for use in biological field studies of burrow and cavity nesting species (Moriarty & McComb 1982, Purcell 1997). A specialised scope ("burrowscope") developed by Dyer & Hill (1991) ("Prototype A" for the purposes of this report) is an instrument designed for inspecting burrows typically used by seabirds for breeding. The burrowscope has an infra-red light source and sensitive camera, wired through a three metre length of hose, that can be manually inserted down a burrow tunnel. A picture of the burrow contents is projected on to a video monitor held at the burrow entrance. Burrowscopes have been used around New Zealand in breeding studies of grey-faced petrels *(Pterodroma macroptera),* tuatara *(Sphenodon puncatatus)*, West land petrels *(Procellaria parkinsoni),* Chatham Islands taiko *(Pterodroma magentae)* (Graeme Taylor, pers. comm.), Hutton's shearwaters *(Puffinus huttoni),* kea *(Nestor notabilis),* as well as for our study of sooty shearwaters (Titi, *Puffinus griseus).* Despite the increasing use of burrowscopes in New Zealand and elsewhere, there are few studies of their accuracy, and of the way different designs might alter detectability of burrow occupants.

The Kia Mau Te Titi Mo Ake Tonu Atu - Keep the Titi Forever research programme aims to investigate the sustainable harvest of sooty shearwater chicks on the Rakiura Titi Islands (Moller 1996, de Cruz *et al.* 1997, Taiepa *et al.* 1997). It also monitors South Island mainland colonies which are threatened by predation from introduced mammals (Marchant and Higgins 1990; Hamilton & Moller 1995; de Cruz *et al.* 1997; Hamilton in press. a). Monitoring and comparing sooty shearwater ecology and behaviour at both harvested and non-harvested sites complements measures of reproductive and survival parameters to predict population trends. The long-term study will help ensure the persistence of both sooty shearwaters and the practice of muttonbirding, which is culturally important for Rakiura Maori. Our studies will help guide the restoration of mainland coastal ecological communities (Jones *et al.* 1997). A standardised "burrowscope", based on the design of Dyer & Hill (1991), is now used in the research programme to survey all sooty shearwater study sites.

The first burrowscope used in the *Kia Mau Te Titi Mo Ake Tonu Atu* programme was built by Paul Jansen of the Department of Conservation (DoC) in 1993 ("Prototype B"). Successive equipment failures have forced several modifications and improvements to be carried out. As new technology develops, burrowscope design improvements are likely to continue so that the accuracy and precision of results obtained can be improved. There is a need to record what has been trialled to provide useful information that will save time and effort for other researchers intending to use and/or develop this equipment for their own research needs. A description of the burrowscope design can also assist other research teams to save costs.

Dyer & Hill (1991) imply absolute confidence in the accuracy of the burrowscope for detection of wedge-tailed shearwater *(Puffinus pacificus)* eggs and chicks. The recent research of sooty shearwaters breeding on The Snares challenges this inference (Hamilton *et al.* unpubl. a). Burrowscopes work best on simple burrow systems with one tunnel to a single nesting chamber. More complex burrow systems create problems of accuracy and precision of results (Hamilton subm.; Hamilton *et al.* unpubl. a). This report is intended to provide a detailed description of a burrowscope and operational methods, the difficulties encountered, modifications and reasons for them. It will also signal potential data biases that will affect population and breeding inferences. A current 1997 costing of the best design and any alternatives was included.

2. Burrowscope designs

2.1 "PROTOTYPE A": SPRING TENSIONAL CABLE AND BALL JOINT

The prototypes described here contain the major elements that have been trialled in several different burrowscopes. In these burrowscopes, a small camera lit by infra-red light emitting diodes (LEDs), is contained in an aluminium cylinder ("camera-head" unit).

For Dyer & Hill's (1991) original burrowscope prototype (Prototype A), an initial problem was the LED outlets becoming covered in sand during insertion into a burrow tunnel (i.e., sand build-up while pushing the camera along the tunnel floor). They partially overcame this problem by permanently raising the camera inside the camera-head casing at a 25° angle and supplying a means of remotely manipulating the angle of the camera-case. Camera-head movement is important so that the camera can be scanned around the inside of a tunnel as well as assisting burrowscope operators to negotiate mud or obstacles (e.g., rocks, tree roots, ledges) down a burrow. Remote manipulation of the camera-head in the Dyer & Hill (1991) model was achieved through spring tensional cable and a ball joint pivot. This could be controlled at the monitor end of the burrowscope and was meant to allow camera-head movement in all directions (i.e., more than one axis). Apparently this was not entirely successful (although reasons why were not stated) and did not provide effective movement (Dyer & Hill 1991).

2.2 "PROTOTYPE B": HYDRAULIC CONTROL

In the construction of Prototype B the main modification of the Dyer & Hill (1991) model was to use a hydraulic propulsion system with a water and antifreeze medium for remote manipulation of the camera-head. A cylindrical control handle at the monitor end of the hose could be moved only on one axis to force movement of the camera head.

Fluid loss and air intake through cracks and splits in hoses or leakage around pistons resulted in a loss of camera-head movement, because air expands and contracts more easily under pressure than fluid. The continual rotation and twisting of hydraulic hoses also caused splits and medium blockages. Another fault encountered with the hydraulic system was stress on mechanical and electrical parts. Substitution with better quality or more robust mechanical/hydraulic parts would have been expensive and was unlikely to have solved the problems. Prototype B was abandoned after a season of use due to the number of occasions the scope required field repairs (approximately 50) and major workshop overhauls (two).

2.3 "PROTOTYPE C": CABLE CONTROL

The most important change to the next design was to revert to cable control of camera case movement. We also took this opportunity to substitute other components in order to reduce the likelihood of burrowscope breakdowns.

The new burrowscope model, Prototype C (Appendix 9.1), was largely custom-built around two pieces of retail equipment (camera and monitor). Brass and steel components in previous prototypes were replaced with aluminium and stainless steel as they were much lighter and more durable. The total weight of the burrowscope, including the 12 volt battery, is 8.5 kg. Field repairs of the cable burrowscope were minimal (approximately five in the 1994/95 season) and involved re-adjustment of cable tension. Only once during the season was there a need for the scope to be seen by the workshop personnel (to replace worn electrical wires).

A custom-built monitor case (Appendix 9.2 - C) was made to contain the larger monitor screen (140 mm x 133 mm compared with the previous 100 mm x 90 mm screen) of the Prototype C burrowscope, as no suitably-sized cases were available on the market. It was thought a larger screen would give better viewing (and therefore more precision in results) for burrowscope operators. The video monitor is a standard security monitor with a 5.5 inch (125 mm) picture tube and gross weight of 4 kg. The 12 volt battery slots into a space in the base of the monitor case and has direct-contact electrical connections compared with the previous two monitor case designs which required positive and negative wires to be manually connected to the battery lugs. The camera used is a 1/4 inch (6 mm) PCB & encapsulated CCD black and white standard security camera weighing 24 g (Appendix 9.3 - a). The small size of the camera and the 3.8 mm lens minimises the size of the casing required and subsequent stress on mechanical parts. The camera is smaller than those used in earlier prototypes and continuous technical developments will mean even smaller cameras will be available for future burrowscope constructions. It is lit by a unit consisting of three wide-beam and three pinpoint infra-red LEDs (Appendix 9.3 - b). The casing for the camera and LED unit was specially manufactured from a solid aluminium cylinder. This contains the camera and lens, LED unit and circuit board and has a custom-built glass front cover ("camera-head"). Initially, plastic front covers were used but they scratched easily and caused the projected image to be blurred. The glass cover is less easily abrased and maintains picture quality.

The camera-head is manipulated on one axis using a similar system to motorcycle control cables (standard Bowden™ cables) (Appendix 9.4). By bending the control handle in one direction, the camera-head can be inclined the same way. When inserted into a burrow tunnel, the camera-head can either be moved from side to side or up and down by rotating the hose to acquire the movement that is required. The camera has just over 90' of movement (i.e., 45' each side of neutral) using the cable system.

The cable system and camera extension cord is contained within a flexible corrugated plastic drainage hose (3.3 m long, diameter = 4.8 cm). The extension cord used between the camera and monitor should be long enough to enable maximum extension of the camera-head down a burrow. A connection cable plugs into the control handle end of the hose and connects (also with a plug) to the monitor case (i.e., monitor and power source). Neoprene, silicon and insulation tape are used at each end of the hose to protect the wiring and cable system from field conditions. Plastic augers (single strips of plastic surrounding the hose in a "cork-screw" fashion) can be attached at intervals along the hose to assist the entry of the camera-head and hose into tunnels.

2.4 "PROTOTYPE D": USE OF AN EYE-PIECE MONITOR

Another version of burrowscope was constructed by Department of Zoology workshop staff for a study of Hutton's shearwaters. Its main aim was to use only one operator instead of the usual two required for operation of Prototypes A-C (R. Cuthbert, pers. comm.). An eye-piece monitor and camera were bought as one unit (DYNA-Image™ CCD video camera and viewfinder) with a three metre length of connecting cable. The eye-piece monitor was mounted on a helmet which allowed free movement of the operator's hands. Attempts were made to lengthen the three metre connecting cable because fitting the camera to the helmet decreased the length available for burrow insertion. Due to the manufacturer's design, lengthening or adjusting the connecting cable resulted in reduced picture quality. However, the major failure in this burrowscope design was eye strain resulting from the monitor being continuously in front of one eye.

2.5 VARIATIONS ON MONITOR CASING TYPES

For the usual two-person operator burrowscope, three different monitor cases (which contain the monitor, circuitry and 12 volt battery) have been used in burrowscopes built (Appendix 9.2). The first (Appendix 9.2 -A) was a Pelican™ waterproof case which had the monitor screen and circuitry fixed in the lid of the case with the 12 volt battery held inside.The second (Appendix 9.2 - B) was bought from an electrical supplier as a plastic switchgear box and the monitor was fixed in the bottom of the case alongside the 12 volt battery. Glare on the clear plastic outer casing was an increased problem with this model as was condensation inside the case, although this was solved with the inclusion of a small bag of silica gel crystals. To avoid over-exposure of the screen's image by the sun, the monitor operator's head and the monitor itself needed to be covered with a cloth hood.

2.6 COST

The total cost of constructing a Prototype C burrowscope is currently estimated at NZ$1990 GST excluded (Appendix 9.5).This is much cheaper than the other prototypes (approx.NZ$5000 for Prototype B and NZ$3750 for Prototype D), largely due to decreased labour time. With a large amount of custom-built componentry, retail costs can be cut. However, we caution that initially a large amount of time is spent developing the design and techniques and refining methodology. This may be a necessary investment for any new research team or when operating in a different burrow system. Constructing subsequent burrowscopes of the same prototype is more efficient. For instance, it now takes three practised technicians 3-4 days to build a new Prototype C burrowscope compared with 2-3 weeks for the original construction.

3. Burrowscope operation

Operation of the burrowscope is most efficiently accomplished by two people - a monitor operator to view the image, manipulate the camera-head using the control handle and relay instructions to the second person (hose operator) who inserts the camera-head and hose down the burrow tunnel.

If the camera-head becomes stuck and progress into the tunnel ceases, the hose can be rotated and the camera-head manipulated to ease its passage. Tunnel corners and obstacles near to the burrow entrance are easy to circumvent if the hose operator inserts their arm as far down the burrow as possible to gain maximum leverage and camera-head movement.

Successful viewing requires systematic coverage of the side walls both while inserting and withdrawing the camera-head. When the burrowscope is pulled out, an egg or chick is sometimes seen which had been missed while going in. Such misses result from an egg or chick being obscured in a side chamber or partition, from inadvertently having pushed past them in a tunnel, or from movement by the chick. The camera-head can be scanned back and forth while still in hand and, once further down the tunnel, can be rolled back and forth by twisting the hose near the burrow entrance. Plastic augers provide a "cork-screw" effect when rotated to assist the movement of the camera down the burrow. These are most efficient in a sand environment but can hinder progress by becoming caught on roots and rocks. Nesting material and substrate often adheres to the front of the camera-head. Debris can sometimes be dislodged by gently shaking or rolling the hose and camera-head, but often the burrowscope needs to be withdrawn entirely from the tunnel to have material wiped from the front before the burrow is probed for a second time.

4. Factors affecting burrowscope operation

Throughout the 1996/97 breeding season, the use of four burrowscopes (operated by combinations of 13 different researchers) has enabled more than 4200 burrow entrances in sooty shearwater study colonies to be monitored (de Cruz *et al.* 1997). The camera-head can often be manoeuvred more than two metres down a tunnel to view a nest. Anywhere between 40 and 100 burrow entrances can be burrowscoped per day depending on degree of burrow complexity, tunnel lengths, occupancy rates, operator expertise, site and weather conditions. In study sites where tunnels are connected together in large burrow complexes (Hamilton subm.; Hamilton *et al.* unpubl a.), more time is needed to work out the connections and nest locations than for sites where burrows are simple and short. If a large proportion of burrows are occupied, it usually takes less time to survey a study site. When there are many unoccupied burrows, more time is needed per burrow to check that an occupant has not been missed. Likewise, burrows with "unknown"occupancy take more time to burrowscope because a thorough attempt is needed to negotiate the obstacle and check the occupancy status of the burrow.

When a burrow occupant is viewed on the monitor screen, the burrowscope is withdrawn from the burrow because disturbance or damage to the egg, chick or adult would result from trying to push the burrowscope past them. It may be that other nests are present behind the one first encountered, so the overall number of nests present will be underestimated.

Burrowscope operator expertise is a crucial factor in successfully obtaining breeding data with the burrowscope. The main requirement is patience. A methodical search of the burrow for side chambers or branches is essential. Temperament of the operator is therefore likely to influence the results. For the monitor operator, a few days is needed to gain the basic skills of interpreting what is viewed on the monitor screen and delivering correct instructions to the hose operator. Varying levels of enthusiasm, effort, perseverance and physical fitness, particularly of the hose operator, could also contribute to the success of the burrowscope. There is a need to investigate the influence of inter-researcher variability on burrowscope data reliability. It is recommended that, when possible, the same operators are used for the work when trends in burrow occupancy are being investigated.

Different weather conditions, especially if uncomfortable for the burrowscope operators, may also affect the burrowscope results. If ground conditions are wet, the camera view is usually obscured by mud and/or condensation and this can reduce reliability of results. Therefore, it is best to avoid working with the burrowscope during bad weather.

5. Burrowscope data biases

5.1 HYDRAULIC VERSUS CABLE MANIPULATION (PROTOTYPE B VERSUS PROTOTYPE C)

Data on unoccupied and unknown burrows were obtained using a burrowscope for the second burrowscope survey (early chick stage) of the 1993/94 and 1994/95 seasons for South Island mainland colonies and Poutama Island (a Rakiura Titi Island). In 1993/94, Prototype B (hydraulic control of the camera-head) was used, and in 1994/95 the current design, Prototype C, (cable control of the camera-head) was used. On the mainland almost exactly the same sample of marked burrows were examined in the two years so the differences between years will mainly reflect the burrowscope design rather than change in burrow architecture between years. On Poutama Island sample size was doubled in 1994/95, so differences between years may reflect burrowscope design, different burrow structures sampled, or both.

The proportion of burrows where the nesting chamber could not be successfully viewed using the burrowscope (i.e., burrow occupancy classified as "unknown" for whatever reason) was not significantly different between Prototype B or Prototype C on Poutama Island ($\chi^2 =$ 3.223, d.f. = 1, p= 0.0726). However, the cable scope had proportionately half the unknowns of the hydraulic system at mainland sites (Appendix 6 - $\chi^2 =$ 5.730, d.f. = 1, p= 0.0 167).

5.2 REASONS FOR FAILURE TO DETECT OCCUPANCY

Study site conditions, substrate type (e.g., sand, soil), substrate moisture content, the presence/absence of obstructions (e.g., nesting material, rocks, tree roots) and the nature of the burrow (e.g., slope, corners, ledges, dirt clumps) may all affect the manoeuvrability of the burrowscope down a tunnel. Physical factors which affect the successful manoeuvring of the burrowscope to view burrow occupants were classified as: tunnel corner (TC), tunnel length (TL), tunnel width (TW), camera digging into the substrate (CD); and access prevented by obstacles (OS) (i.e., tree roots, rocks, or a ledge). Sites were surveyed using a burrowscope eight times over three breeding seasons (1993 - 1996) on the mainland, and four times in two seasons (1994 and 1995) on Poutama Island. At one mainland site with a sand substrate, data were collected for the causes of 55 unsuccessful burrowscoping attempts (i.e., "unknown" burrows where neither an egg nor chick was found and the end of the burrow was not reached); at mainland sites with a soil substrate, the causes of 66 unsuccessful burrowscoping attempts; and at Poutama Island, the causes of 104 unsuccessful burrowscoping attempts.

The most common reason for failure to determine burrow occupancy with both prototypes was the inability to manoeuvre the scope around a tunnel corner. Tree roots, rocks and ledges also prevented access (Appendix 9.7). The proportion of burrows with "unknown" occupancy at each site due to tunnel corners ($\chi^2 =$ 37.755, d.f.= 2, p <0.0001) and the camera-head digging in ($\chi^2 =$ 20.930, d.f.= 2, p <0.0001) were significantly different. Poutama Island burrows were more restricted by corners and obstacles in the tunnel, i.e. the proportion of burrowscoping attempts that failed to get around either a tunnel corner or an obstacle was significantly higher on Poutama Island (32.7%; n = 116) than on mainland sites (8.4%; n = 23) ($\chi^2 =$ 53.267, d.f.= 1, p <0.0001).The Snares site was excluded from this analysis because reasons for an "unknown" occupancy there were not recorded.

Improved camera-head manipulation could improve movement of the burrowscope around a tunnel corner or these obstacles. However, the proportion of the "unknown" occupancy burrows that were unsuccessfully burrowscoped because of corners or obstructions did not differ significantly between prototypes on Poutama Island ($\chi^2 =$ 1.497, d.f.= 1, p= 0.2211) or the mainland ($\chi^2 =$ 0.671, d.f.= 1, p= 0.4126).

The main advantage of Prototype C was the minimisation of breakdowns and consequent increased number of burrows that could be prospected in the time available. This allowed doubling of sample sizes attainable in one season on Poutama Island (Appendix 6).

5.3 VARIATION IN BURROWS OF "UNKNOWN" OCCUPANCY BETWEEN AREAS

Breeding data were collected for the first cable burrowscope survey in the 1994/95 season at sites on Poutama Island and the South Island mainland, and the first burrowscope examination of the 1996/97 season on The Snares. On Poutama Island, from the total number of burrows surveyed, there were six times as many "unknown" occupancy burrows (24.9%, n = 526) than for mainland sites (4.4%, n = 6,78) and the Snares islands (4.4%, n = 367) ($\chi^2 =$ 147.12, d.f.= 2, p <0.0001).These differences could reflect variations in bird occupancy between islands, difference in the detectability of the birds that are present, or some combination of both. For example, if burrows are more crowded on the Snares, there is more likely to be at least one bird close to the burrow entrance, and such birds are more likely to be detected.

To counteract this differential occupancy effect, only the "unoccupied" burrows (burrows that were inspected entirely but no egg, chick or adult found) and those classed as "unknown" were compared. When occupied burrow frequencies were removed, proportions of "unknown" occupancy burrows were still significantly different between mainland (11%, n = 30), Poutama Island (35%, n = 130) and The Snares (11%, n = 15) sites ($\chi^2 =$ 67.846, d.f.= 2, p <0.0001).

5.4 THE IMPORTANCE OF BURROW LENGTH AND COMPLEXITY

The burrowscope operators recorded the distance from the burrow entrance that any egg, chick, adult, end wall or obstruction was encountered. Half metre graduations were marked off on the burrowscope hose for this purpose and distances between each graduation measured with a half metre rule. The proportion of all unoccupied burrows for which the burrowscope could not gain entry to all parts of the tunnel increased for longer burrows at all three study areas (Appendix 9.8). Second order polynomials increased r^2 values 0.027 compared to a linear model on Poutama Island, and by $\leq$ 0.001 at the two other sites. Accordingly the simpler linear models were used for the three areas. The small sample size of "unknowns" from The Snares (n=15) is potentially the reason for a poor linear fit ($p = 0.428$, d.f. = 9) there, but there were highly significant ($p < 0.01$) fits to linear models at Poutama and the mainland sites (Appendix 9.8).

Poutama Island experienced the greater proportion of "unknowns" in burrows less than 1.5 m than elsewhere. The Snares generally experienced lower unknown occupancies than the other sites, but there was one outlier around burrow length 1.75 m (Appendix 9.8). Larger sample sizes are needed for The Snares to better characterise its proportion of unknown burrows for a given length compared to elsewhere.

Eighty-eight percent of "unknowns" on Poutama Island in the 1994/95 season were because of burrow corners or obstructions (Appendix 9.7). Accordingly we examined the proportion of unoccupied burrows that had unknown occupancy as a result of failure to negotiate a corner or obstacle at different lengths from the burrow entrance (Appendix 9.9). Again the longer burrows were more likely to have corners or obstructions preventing penetration by the burrowscope (Appendix 9.9), but in this instance data from the mainland fitted a second order polynomial ($r^2 = 0.97$) better than a linear model ($r^2 = 0.85$). On Poutama Island a linear model had very nearly as good a fit ($r^2 = 0.62$) as a polynomial ($r^2 = 0.64$). The increased chance of failure to negotiate corners at increasing distances from the burrow entrance could partly reflect more corners or obstacles being present deeper in burrows. However, we suspect it is more simply a reflection of difficulty in manoeuvring the camerahead once the full length of the flexible burrowscope hose is inserted deep within a burrow. The proportion of "unknown" occupancy burrows caused by obstructions or corners began to merge in burrows longer than 2 m (Appendix 9.9). This suggests that the burrow length became the prime inhibiting factor preventing complete inspection of burrows beyond 1.5 to 2 m, but that this effect is indirectly caused by inability to get around the corners or obstacles at these extreme depths. Burrow length may therefore account for a large part of the differences in proportions of "unknowns" observed between areas. There was a significant difference between mainland soil and sand sites and Poutama Island in the "unknown" proportions attributed to "tunnel length" ($\chi^2 = 20.266$, d.f.= 2, $p < 0.0001$), but no significant difference between mainland sites in sand and mainland sites in soil ($\chi^2 = 2.690$, d.f.= 1, $p = 0.101$). However, increased failure rate due to corners and obstructions for a given length below 1.5 m on Poutama compared to mainland sites (Appendix 9.9) demonstrates that it is not simply length of burrows that determines detection rates in different places. Perhaps (i) there are more corners per unit burrow length on Poutama, (ii) corners are sharper or obstacles are bigger on Potttama, (iii) tunnels are narrower on Potttama so that negotiation around a corner is more difficult, or (iv) some combination of these factors operate.

A greater complexity of burrow systems on Poutama Island was obvious from the divergence of burrows. At least 35% (n = 382) of burrow entrances on Poutama Island divided into more than one tunnel, while on the mainland the figure was only 9 % (n = 617).

6. General discussion and recommendations

6.1 OPTIMAL BURROWSCOPE DESIGN

Study sites in the *Kia Mau Te Titi Mo Ake Tonu Atu* programme are mainly in isolated locations, often on offshore islands. It is usually a huge and expensive logistic task getting to study sites, and researchers can be isolated for weeks at a time. In these study conditions, only basic equipment and expertise exist for burrowscope repairs and therefore only basic maintenance can be carried out. Construction of reliable burrowscopes robust enough for a range of arduous field conditions is important in order to minimise the loss in time and resources spent on repairs. Burrowscope breakdowns during the 1993/94 season resulted in an insufficient amount of data collection for the egg stage, and patchy data over the rest of the breeding season. More than two and a half times as many burrows were examined over the same period on Poutama Island in the following season when a remote cable system was used. There is also some indication that better movement of the camera head in Prototype C halved the number of "unknown" burrows on the mainland. It is suspected that a similar effect was not registered on Poutama Island because a larger group of burrows with potentially different burrow characteristics were sampled in the second year. Accordingly, Prototype C is by far the best design available so far, and is recommended for use from now on.

Experience indicates one or two seasons are needed to realise problems and customise the burrowscope to the study and species requirements. Burrowscope design differences will interact with site factors (burrow lengths, widths, corners and obstacles), so what is conducive to one study site may be less satisfactory in others. Research on smaller burrowing seabirds like the Hutton's shearwater requires a smaller scope to suit their burrow characteristics. Augers useful in a sand substrate became a hindrance in this rocky alpine environment (R. Cuthbert pers. comm.). Therefore customising the design trade-offs becomes crucial to the success of the monitoring technique in different studies.

Future burrowscopes may include a form of thermo-regulator or heartbeat recorder (Warham & Wilson 1982) to ascertain the presence of a burrow occupant (Hamilton *et at.* unpubl. a) for burrows where the burrowscope camera cannot be manipulated to view all parts of the burrow. Infra-red heat sensors may be a future tool for determining the presence of an animal underground. Improvements on the remote control of the camera may also assist with manipulation of the burrowscope around obstacles and down longer convoluted burrows.

Continued improvement and precision of the burrowscope design may increase the success rate of nest detection. Refining and developing the construction of the burrowscope is probably the key to obtaining accurate baseline occupancy data (Hamilton subm.). However, even our best design could not determine the occupancy of about a third of the burrows on Poutama Island. This suggests there is a maximum burrow complexity in which a burrowscope can operate efficiently, whatever its design.

6.2 THE IMPORTANCE OF BURROWSCOPE PRECISION AND ACCURACY

Precision of the burrowscope is estimated from the consistency of results from repeated burrowscope checks on a fixed sample of nests. Inaccuracy of the burrowscope (i.e. consistently missing a sub-sample of the nests in a study site) is not so important for those issues where the aim is trend analysis. If the burrowscope is inaccurate but precise, its results would still be useful as a relative index for monitoring population trends provided that the nesting chambers most accessible to the burrowscope are nether preferred nor avoided by the birds.

Accuracy (i.e. whether or not the presence of a nest is correctly detected) is needed to estimate the proportion of chicks harvested and the absolute abundance of nests in different colonies. Accuracy is also needed for reliable estimates of breeding success. The *Kia Mau Te Titi Mo Ake Tonu Atu* research programme needs accurate estimates of breeding success to predict demographic trends, as well as accurate estimates of burrow occupancy to detect population changes and thereby check the demographic models themselves. The dilemma is that this preliminary study, and that by Hamilton *et al.* (unpubl. a), have identified several potential biases of burrowscopes, but the alternative methods of obtaining the necessary data are certainly even worse (Hamilton, in press. a & b). Traditional methods to determine sooty shearwater burrow occupancy from sound, smell, sign at burrow entrance, or probing with a stick or wire have proved to be far too inaccurate to reliably index population size or breeding success. Inspection hatches cause condensation to accumulate on lids above the nest (P. & J. Davis pers. comm.), decrease the stability of substrate over the burrows (P. Lyver pers. obs.) and can allow water to enter. Therefore, customised burrowscopes are a much needed tool in the study of burrow nesting seabirds.

Temporal comparisons of burrowscope data from one place are more likely to be reliable than comparisons between different places, because the proportion of nests missed by the operator is likely to be affected by the complexity of the burrow system. The length and number of tunnel connections, layering of burrows, tunnel corners and the obstacles encountered are all potential sources of biases in spatial comparisons. Our study has demonstrated large differences in proportion of burrows for which occupancy was not determined, mainly because of variation in burrow complexity and length.

At mainland sites, a very low proportion of burrows had "unknown" occupancy compared with the Poutama Island sites (with more complex burrow systems). The proportion of "unknown"burrows on Poutama Island that were less than 1.5 m long was far greater than burrows of similar length on the mainland. Burrow corners and obstructions were identified as the main cause. Therefore, it is not length alone that affects precision and accuracy. This difference in sites most probably occurs due to the nature of the substrate and overlying vegetation. The combination of a peat substrate and substantial *Olearia angustfolia* and *O. lyalli* root systems would allow for greater burrow complexity on Poutama compared with the predominantly grass cover (rank exotic grasses and marram grass - *Ammophila* spp.) on sand and soil substrates of the mainland.

In burrows greater than 1.5 m long the flexible hose became very difficult to manoeuvre, and length of burrow became the over-riding determinant of entry and examination. Areas with very different proportions of burrows greater than 1.5 m long will have very different proportions of "unknown"occupancy.

6.3 THE POTENTIAL IMPORTANCE OF BURROW PREFERENCE

Burrows where researchers were unable to ascertain occupancy using the burrowscope (i.e. "unknown" occupancy burrows) had physical characteristics differing from others (e.g. greater burrow lengths, corners or obstacles). There may be a need for research to investigate the quality of birds and their productivity from different burrows, as this may be important for predicting harvest impacts. Such a study would be important for determining whether a biased sample is being obtained with the burrowscope. If burrows accessible by the burrowscope are favoured by the birds, a potential problem is that any changes in the population may be obscured by successive burrowscope counts. For instance, a decline in the overall population may not be recorded simply because birds nest in the preferred burrow types for which occupancy can be detected by the burrowscope. Had all burrows been equally accessed by the burrowscope, the true extent of any such decline would have been detected. Similarly, if young breeders are more inclined to fail in breeding attempts and such birds use shorter or less complex burrow systems, then the burrowscope will reveal an under-estimate of breeding success. Alternatively the true breeding success might be over-estimated if failed breeding attempts in deeper "unknown" chambers further from the entrance are not monitored.

There are as yet no quantified inferences about whether sooty shearwaters prefer burrows with particular physical characteristics, or whether they compete for preferred burrows. Accordingly we can not yet advise whether the very high proportion of unknown burrows in some places will significantly bias population inferences from the burrowscope data.

6.4 WAYS OF INCREASING PRECISION AND ACCURACY

Consistency with equipment and operators is very important in order to increase the precision of burrowscope results throughout a season, or compare between seasons. The burrowscope must be in good working order and have a standardised design. We recommend that each set of equipment is numbered so that operators can record its identity alongside the data they gather with it. Any effects of minor variation in the equipment on data could potentially then be traced and factored out of statistical comparisons. Efforts should be made to ensure new equipment is not brought in unless large gains in accuracy or efficiency will result. If such a change is deemed desirable, the new and old equipment should be used alongside one another for sufficient time to obtain a benchmark of their relative performance. Surveys should ideally be done only in dry weather to minimise the effects of wet substrate, water entering equipment causing failure, and unpleasant working conditions. Operator persistence is an important factor. The different number and experience levels of the burrowscope operators is also likely to play a role in the accuracy of results obtained. Experience is needed to efficiently manipulate the burrowscope into the tunnel or cavity and identify the image the video monitor. There are preliminary indications fromThe Snares and Whenua Hou (Codfish) sooty shearwater studies that operators failed to detect some chicks through inexperience and burrowscope design restraints (Hamilton *et al.* unpubl. a & b).

6.5 CORRECTION FOR BURROWSCOPE INACCURACIES

Burrows at The Snares also had a high degree of complexity but nevertheless had a low proportion of "unknown" burrows. This may be because of a large sooty shearwater breeding population (Warham &Wilson 1982) which most likely has a higher density of nests. Therefore, a higher proportion of the entrances burrowscoped will yield an occupant or nest. We withdrew the burrowscope once we found an occupant, but it is possible that other occupants were also present but missed in such burrows. Indeed, at an experimental study site on The Snares, researchers missed up to 34°% of nests using the burrowscope in one small plot that was excavated to check the accuracy of the burrowscope (Hamilton *el al.* unpubl. a). Accordingly the proportion of the burrows that were unknown cannot simply be used to index the "miss rate" and thereby mathematically correct occupancy rates in different areas. Bird density and burrow occupancy are likely to interact with burrow geometry to affect the proportion of eggs and chicks missed by the burrowscope. As population trend and burrow occupancy are themselves key parameters for the sooty shearwater research project, we need to find an independent method of estimating error rate in burrowscope data from different study areas. Some measures of burrow geometry determined during the survey could potentially be used indirectly to estimate the proportion of birds missed by the burrowscope. For example we could measure the number and sharpness of corners, the depth and length of tunnels, their degree of divergence (splitting) into separate tunnels, or the width of the tunnels or gallery spaces for a subsample of burrows as the burrowscope is inserted. If these parameters can be shown to alter the probability of detection of birds by a standard amount, it is possible that observed bird densities can be "corrected" to estimate the absolute abundance of eggs or chicks present.

A pilot study was conducted by Hamilton *et al.* (unpubl. a) in which burrows were dug up after being burrowscoped. This confirmed the poor accuracy and precision in occupancy data obtained using the burrowscope at The Snares that we have found elsewhere by the present study. However, the digging study was conducted on only one small site on The Snares, and it is possible that localised high density of sooty shearwaters there caused extremely complex burrow connections. More digging experiments will be needed on The Snares and elsewhere to determine whether the burrowscoping technique is useable, and whether a "correction factor" of the nature described above can be developed.

Digging investigations are destructive, so it is important to minimise the number and size of areas investigated. Accordingly the *Kia Mau Te Titi Mo Ake Tonu Atu* research team is preparing a request to the kaitiaki and DoC for permission to conduct a series of tests of the ability of the burrowscope team to detect dummy eggs inserted (via inspection hatches over nesting chambers) within burrows over the winter period when no sooty shearwater eggs, chicks or adults are present. The burrowscope operators will not know how many dummy eggs have been placed, nor their distribution, so this test will measure their absolute detection rate in an unbiased way. These trials will also test whether a sufficiently accurate correction factor determined from burrow geometry measures exists to correct for the proportion of eggs missed. Unfortunately chick movement and size may also influence detectability by the burrowscope, and we cannot do dummy chick placement trials. Accordingly some small digging investigations are needed to check error rates of the burrowscope during the chick phase. Until future technology becomes available, use of current burrowscope designs, if possible incorporating a correction factor to estimate missed birds, will be the most reliable technique of establishing burrow occupancy, breeding success and population trends of burrowing petrel species like sooty shearwaters.

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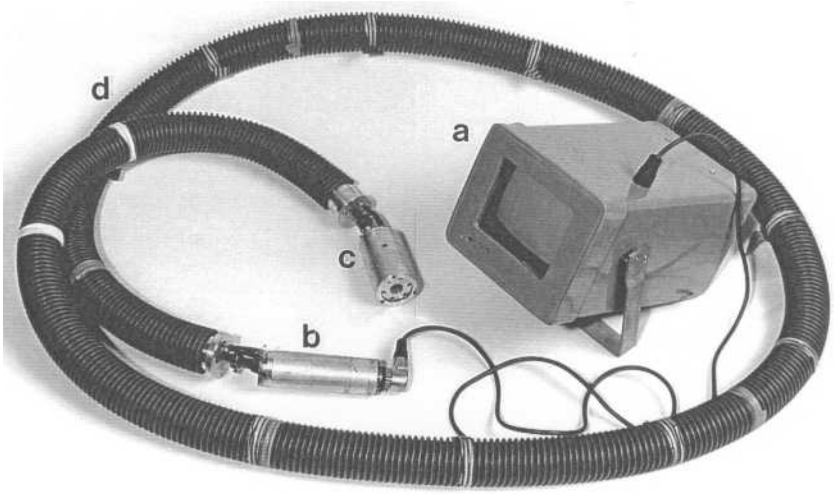
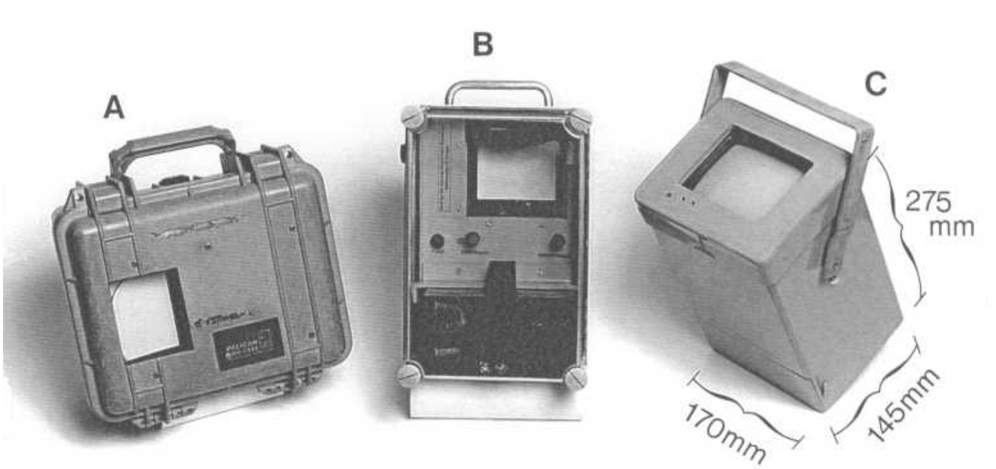
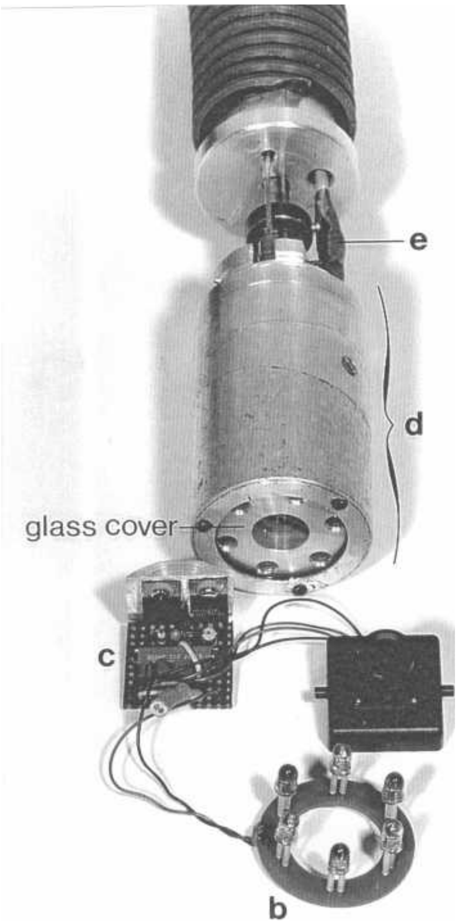
9. Appendices



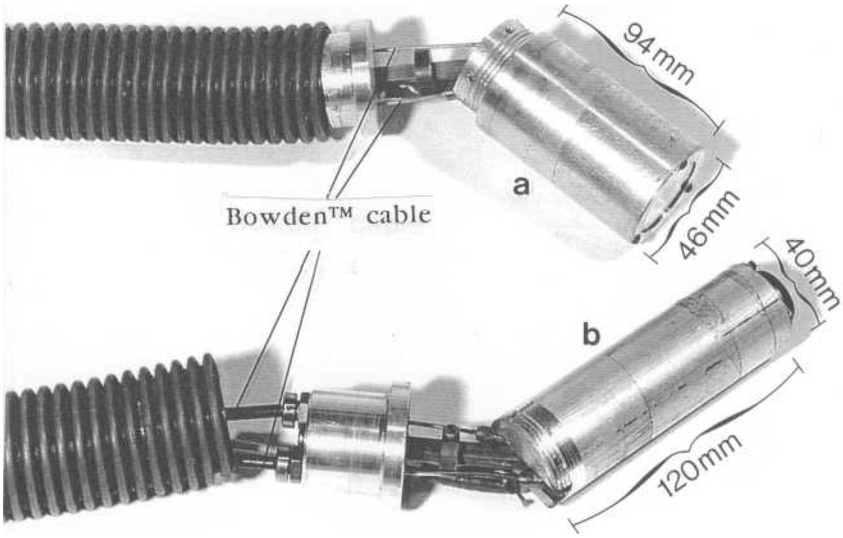
9.1 The burrowscope (Prototype C) used by the Kia Mau Te Titi Mo Ake Tonu Atu programme to collect sooty shearwater breeding data. (a) case containing the monitor and 12 volt battery, (b) the handle for manipulation of the camera head, (c) camera head and light source and (d) the connecting hose which carries the Bowden ™ manipulating cable and power wires.



9.2 The changes of the burrowscope case (A - C) containing the monitor, terminal block and 12 volt battery power source.



9.3 (a) the camera, (b) LED unit and (c) circuit board and voltage and current regulator which fit inside the camera head (d). The camera lens and ring of infra-red LED's are protected by a glass cover. Both the power wires (e) and one of the Bowden™ cables can be seen at the rear of the housing.



9.4 The camera head (a) is connected to the handle (b) by the Bowden™ cables and electrical wires. A sealed flexible hose covers and protects these components but here is drawn back to show construction detail. The handle (b) can be manipulated on one axis only to control camera head movement.

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