MARINE ORNITHOLOGY

Vol. 28 No. 1 2000

HOW PRECISE AND ACCURATE ARE DATA OBTAINED USING AN INFRA-RED SCOPE ON BURROW-NESTING SOOTY SHEARWATERS *PUFFINUS GRISEUS*?

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Received 6 March 1998, accepted 25 August 1998

SUMMARY

HAMILTON, S. 2000. How precise and accurate are data obtained using an infra-red scope on burrow-nesting Sooty Shearwaters *Puffinus griseus*? *Marine Ornithology* 28: 1–6.

An infra-red camera 'burrowscope' has been designed for inspecting burrows and cavities typically used by breeding seabirds. The *Kia Mau Te Titi Mo Ake Tonu Atu (Keep the Titi Forever)* Research Programme in New Zealand aims to investigate the sustainable harvesting of Sooty Shearwater *Puffinus griseus* chicks as well as monitoring mainland breeding colonies which are threatened by predation from introduced mammals. The burrowscope is being used to determine Sooty Shearwater breeding success and to assess population trends. However, there have been preliminary indications that the burrowscope fails to detect some nests down burrows. During incubation, and after completing three repeated, consecutive burrowscope checks of nests, a plot containing 100 burrow entrances on The Snares Islands was excavated to confirm burrow contents. Using the burrowscope, researchers not only missed up to 34% of nests, but the three consecutive burrowscope checks gave divergent results. This pilot study illustrated the potential complex geometry of burrow systems and indicated that the current burrowscoping methodology may be inaccurate and imprecise in detecting Sooty Shearwater eggs, young chicks and pre-fledging chicks.

INTRODUCTION

Studying the breeding biology of burrow-nesting seabirds requires accurate identification of burrow occupants and nest status which can be difficult especially for burrows more than two metres long (Hamilton 1998a). The *Kia Mau Te Titi Mo Ake Tonu Atu – Keep the Titi Forever* Research Programme aims to investigate the sustainable harvesting of Sooty Shearwater ('titi') *Puffinus griseus* chicks as well as monitoring and restoring mainland colonies threatened by predation from introduced mammals (Hamilton 1998a). Monitoring and comparing Sooty Shearwater ecology and behaviour at both harvested and non-harvested sites complement measures of reproduction and survival that help predict population trends. The long-term research programme will help ensure the persistence of both the bird and of 'muttonbirding' (chick harvesting), a culturally important traditional practice of indigenous Rakiura Maori from southern New Zealand.

Historical methods to determine Sooty Shearwater burrow occupancy using sound, smell, and/or sign at burrow entrances, or by probing burrows with a stick or wire, are too inaccurate to index population size or breeding success reliably (Hamilton 1998a, b). A 'burrowscope', originally described in Dyer & Hill (1991), is designed for direct visual inspection of nesting chambers. The burrowscope has an infra-red lit camera at the end of a three-metre length of hose that can be pushed down a tunnel while projecting a picture onto a video monitor at the burrow entrance. Dyer & Hill (1991) believe the burrowscope was well suited to their Wedge-tailed Shearwater *P. pacificus* studies but differing soil types, burrow geometry and soil moisture regimes may influence burrowscope performance. Despite increasing international use of burrowscopes (Dyer & Hill 1991, Purcell 1997, R. Cuthbert unpubl. data), there are no published formal checks of their reliability in determining burrow occupancy and studying breeding biology. There are preliminary indications in Sooty Shearwater research that 'burrowscoping' fails to detect some chicks (Hamilton *et al.* 1996). It is critical, therefore, to assess the error rate of burrowscoping to obtain accurate estimates of burrow occupancy, breeding success, proportion of chicks harvested, and Sooty Shearwater population abundance.

In this pilot study, two types of error were investigated to assess the reliability of burrowscoping. Firstly, burrowscoping precision was assessed by determining the consistency of results among repeated burrowscope checks on a fixed sample of nests. Secondly, burrowscoping accuracy (i.e. whether or not nest presence was correctly detected) was determined by burrowscoping study burrows followed by excavation of the burrows to confirm their contents. If precise, the burrowscope method has utility as a relative index for monitoring population trends. Precision is needed to estimate breeding success and the timing of any egg/chick losses reliably. Burrowscoping also needs to be accurate to estimate the proportion of chicks harvested and the absolute abundance of nests in different colonies.

Because assessing burrowscoping accuracy required study burrow excavation, an area was cleared that could potentially be recolonised. As the time taken for Sooty Shearwaters to recolonise a disturbed area is unknown, monitoring the experimental area will provide information to Rakiura Maori, conservationists and researchers interested in restoring depleted colonies.

METHODS

On Northeast Island, The Snares (48°01'S, 166°36'E) and Whenua Hou or Codfish Island (46°45'S, 167°38'E), Sooty Shearwater study sites were monitored during the 1996/97 breeding season. At two sites, Snares A (containing 311 marked burrow entrances) and Whenua Hou B (containing 174 marked burrow entrances), nest checks were made using the burrowscope during incubation (November/December 1996), young chick stage (January/February 1997) and pre-fledging chick stage (April 1997). Both of these study sites had firm, peaty soil and contained trees. At Snares A, amongst burrows in flatter areas that were not too obstructed by tree roots, a random two thirds had observation holes established allowing access to the nesting chamber. Observation holes were covered with either a wooden hatch or a plug of soil and vegetation (Hamilton *et al.* 1996).

In November/December 1996 on Northeast Island, The Snares, a *c.* 10 × 10 m plot containing 100 burrow entrances was marked out (Snares C). After familiarisation with a large part of Northeast Island, the location and size of the plot were arbitrarily chosen as appearing to have a burrow density similar to the majority of areas under *Olearia lyallii* canopy (the dominant canopy covering *c.* 80% of the island, Rance & Patrick 1988) and for its proximity to the hut. The soil was firm and peaty and the plot contained *O. lyallii* trees. During incubation, all burrows were 'burrowscoped' three times by the same researchers over a two-week period for occupancy, the presence and location of nests, and the presence/absence of an egg.

Immediately after the third burrowscope check, and over five days, Snares C was excavated to determine the proportion of nests missed or recorded more than once during burrowscope surveys. From each burrow entrance, the tunnel direction was identified and a hole was excavated into the tunnel at arm's length from the entrance. This was repeated along the remainder of the tunnel so that all walls of the tunnel and associated tunnel branches could be confirmed. Every egg found was defined as a 'nest'. Eggs were often incubated by an adult and were usually on a pile or scattering of *O. lyallii* leaves and sticks. Each nest site was mapped and measured from any entrances which could possibly have been linked to that nest using the burrowscope. All adults removed from nests were banded and released away from the experimental plot at the cliff edge.

In January 1997, the Snares C excavation was filled-in using the original soil that had been piled at the plot edges. The plot boundary was marked with numbered aluminium stakes. Twenty-two 'starter' entrances (with approximately 20-cm long tunnels) were established in one half of Snares C to provide potential stimulation for enhanced recolonisation. The other half of the plot was filled-in and left with no 'starter' entrances.

In late January 1997 Snares C was visited at night to observe adult Sooty Shearwater behaviour, to record previously banded adults, and to band any new adults using the area. All burrows in the plot were burrowscoped on 30 January and 12 April 1997 to check occupancy and to measure the length of new tunnels. Snares C will be monitored for use and recolonisation over the next ten years and burrows near the plot will be checked to see if they are being used by displaced adults.

RESULTS

Burrowscoping precision in determining overall burrow occupancy and burrowscoping accuracy in detecting nest numbers

At Snares A, the occupants of 101 nests were recorded on each of three burrowscope checks (incubation, young chick and pre-fledging chick stages) (Table 1). An egg or chick recorded during at least one burrowscoping period was considered a nesting attempt. There was a possible total of 221 nesting attempts at Snares A. For the pre-fledging stage, 128 chicks were recorded. At Whenua Hou B, 32 nests were recorded on each of three burrowscope checks (incubation, young chick and pre-fledging chick stages), and there were another 39 possible nesting attempts (Table 1). Of 71 possible nesting attempts, 46 pre-fledging chicks were recorded.

Excavation of Sooty Shearwater burrows in Snares C revealed complex burrow systems with a large number of tunnel connections (Fig. 1). A total of 91 nests, each containing an egg, was uncovered during the excavation. Only five of the 100 burrow entrances led to a self-contained burrow and were not connected to any other entrance. The most complex system connected 21 burrow entrances and contained 23 nests. Many nests could be reached (and therefore burrowscoped) from more than one entrance which meant that some nests were recorded more than once from different entrances during burrowscoping. Some nests were around awkward corners or at such distances from entrances, that they were not recorded during burrowscoping.

For three consecutive burrowscope checks on Snares C, 68 nests were recorded for the first check (seven incorrectly), 76 nests for the second check (16 incorrectly), and 95 nests for the third check (22 incorrectly) (Table 2). Of 91 nest sites uncovered during the excavation, 15 (16.5%) were not found during any of the three consecutive burrowscope surveys. Only 46 (50%) were recorded correctly for all three burrowscope checks. The first two burrowscope checks gave similar proportions of correctly identified nests (67% and 66%, respectively), which increased to 80% for the third burrowscope check (Table 2). However, the third burrowscope check had the highest number of nests recorded twice from two different entrances. For each of the three burrowscope checks, one nest was recorded when it did not exist (Table 2) but each of these was a different nest at each check. The % error in the total number of nests recorded decreased for each subsequent burrowscope check (Table 2).

TABLE 1

At Snares A (n = 221) and Whenua Hou B (n = 71), the number (top row) and proportion (bottom row) of nests that were recorded using the burrowscope during incubation, young chick and pre-fledging chick stages

Study site	[4,5] Egg only recorded	[1,2,5] Young chick only recorded	[2,4] Pre-fledging chick only recorded	[1,2] Egg not recorded; young chick & pre-fledging chick recorded	[3,4] Young chick not recorded; egg & pre-fledging chick recorded	[5] Pre-fledging chick not recorded; egg & young chick recorded	Recorded for each of three burrow-scope checks
Snares A	46 21%	11 5%	7 3%	13 6%	7 3%	36 16%	101 46%
Whenua Hou B	20 28%	2 3%	3 4%	9 13%	2 3%	3 4%	32 45%

A minimum of 11% (sum of [1]) and maximum of 14% (sum of [2]) eggs were unrecorded at Snares A and 16–20% eggs were unrecorded at Whenua Hou B.
A minimum of 3% ([3]) and maximum of 26% (sum of [4]) young chicks were unrecorded at Snares A and 3–35% young chicks were unrecorded at Whenua Hou B.
A maximum of 42% and 35% (sum of [5]) pre-fledging chicks were unrecorded at Snares A and Whenua Hou B, respectively.

TABLE 2

Nest data for Snares C showing the number (top row) and proportion (bottom row) of nests (containing an egg) which were recorded but not actually present (A), recorded twice from different burrow entrances (B), correctly recorded as being present (C), and present but not recorded (D), for three consecutive burrowscope checks over a two-week period during incubation, December 1996

Consecutive nest check using the burrowscope	A. Recorded but not present	B. Recorded twice	C. Correctly recorded	D. Present but not recorded	% error $[(A+B+C) - (C+D)]/(C+D) \times 100^{-1}$	Total number of nests
First check	1	6	61 67%	30 33%	25%	91
Second check	1	15	60 66%	31 34%	16.5%	91
Third check	1	21	73 80%	18 20%	4%	91

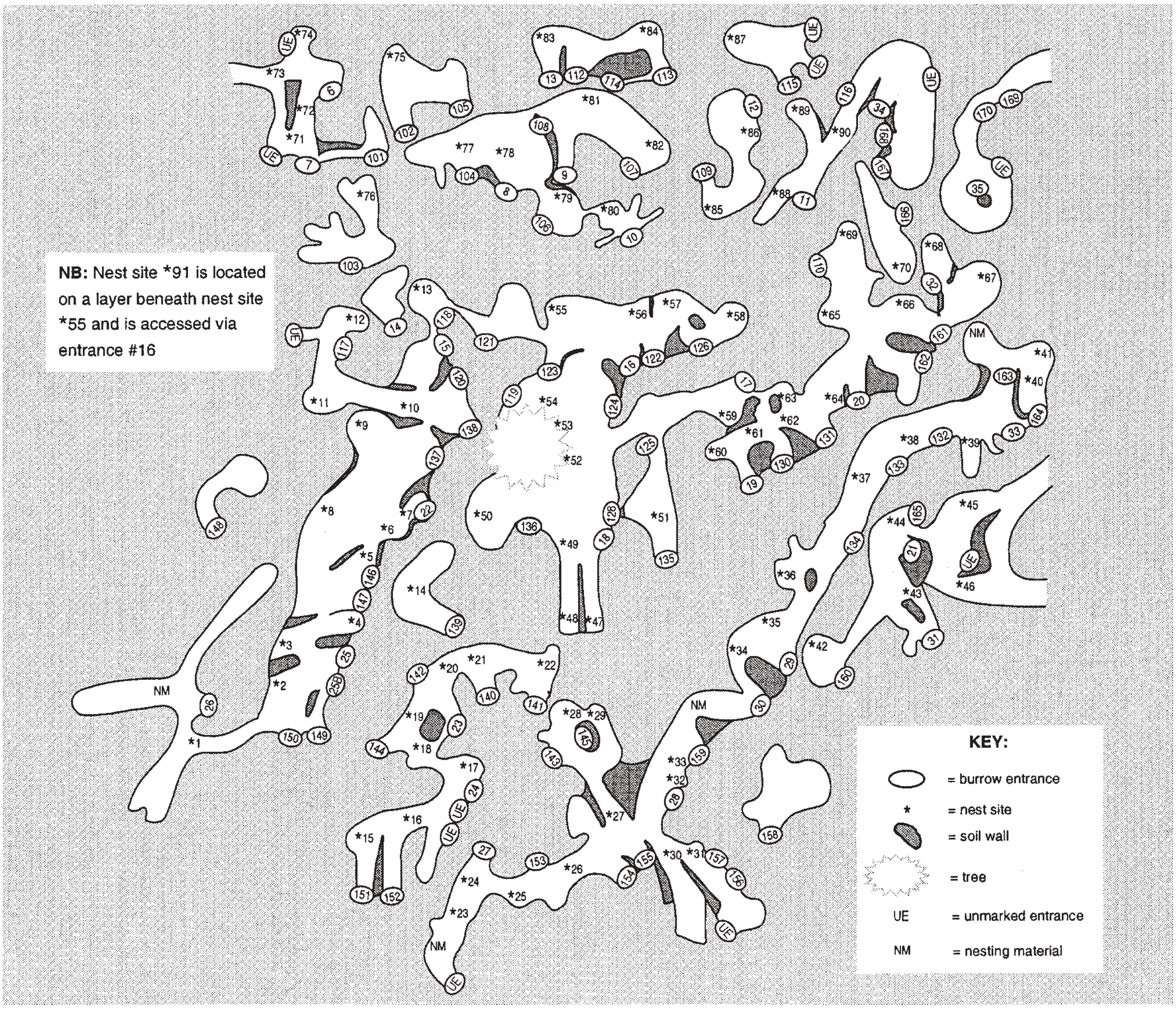

***Fig 1.** The lay-out sketch (from above) of Sooty Shearwater burrows in the* c. *10 × 10 m Snares C experimental plot after the December 1996 excavation of burrows, showing the enormous burrow complexity of this plot, with many different entrances connecting together and leading to many different nest sites.*

At Snares A, 56 burrows were burrowscoped and observation holes were checked during the young chick stage in January/February 1997. Six nests (11%) were detected using observation holes that had not been detected during burrowscoping. At Snares A during the pre-fledging stage (April 1997), of 42 burrows containing nests and with observation holes, seven nests (17%) were detected using observation holes that had not been detected during burrowscoping.

Post-excavation Sooty Shearwater activity

From 03h30–05h30 on 25 January 1997, 43 days after the Snares C excavation was completed and four days after the plot was filled-in, pairs of adult Sooty Shearwaters were observed in mutual preening, vocalising and sitting close together on the surface within the plot and one copulation was observed at *c.* 04h30. Over the two-hour period, 42 adults were caught within the plot, of which 45% were adults banded during the December excavation. From 02h30–05h00 on 26 January 1997 and 20h40–21h40 on 29 January 1997 an additional 16 adults banded during the excavation were recaptured and 64 new adults were banded. Therefore, at least 36% of the original birds removed during the excavation (n = 97) were still active in the same *c.* 10 × 10 m area.

On 30 January 1997, nine days after Snares C had been filled-in, the entrances in the plot were burrowscoped. In the enhanced recolonisation half of the plot, 14 new burrow entrances had been established by Sooty Shearwaters in addition to the 22 'starter' burrows. Twenty-eight new burrow entrances had been established by Sooty Shearwaters in the other half of the plot. The 22 'starter' entrances, originally 20-cm long, had increased to an average tunnel length of 80 cm (SD = 23). The 42 new entrances had an average tunnel length of 82 cm (SD = 36). These lengths were not significantly different from 130 undisturbed and unoccupied burrow tunnels (average length 86 cm, SD = 29) at Snares A at the same time of year (analysis of variance, $F_{2,193} = 0.45$, n.s.). Adult Sooty Shearwaters were present in 19% of the 64 burrows at Snares C in January.

On 12 April 1997, the burrow entrances in Snares C were again burrowscoped. An additional 15 new entrances had been dug since the previous burrowscope check. This gave a total of 79 entrances (all unoccupied) in the plot (including 'starter' entrances), compared with 100 pre-excavation burrow-entrances.

DISCUSSION

Precision of burrowscoping for determining burrow occupancy

This pilot study indicates a lack of precision that could render unreliable the current estimates of Sooty Shearwater breeding success from burrowscoped study burrows at these sites. A large proportion of nests was missed for at least one of the three breeding stages during burrowscope checks made at Snares A and Whenua Hou B. At Snares A, 11–17%, and at Whenua Hou B, 16–23% of nests had no occupant recorded at an earlier check but an occupant recorded at a later check. Maximum estimates assumed both hatching failure and chick mortality occurred and minimum estimates also assumed that movement of pre-fledging chicks occured into burrows other than their original. The proportions of true nest failures in the 'egg only recorded' and 'pre-fledging chick not recorded' categories are unknown. There are also no data on chick movement both underground and above ground and, therefore, no information on how much that factor accounts for the apparent appearance or disappearance of pre-fledging chicks on subsequent burrowscope checks. During Short-tailed Shearwater *P. tenuirostris* nest checks on Fisher Island, north-west Tasmania, chicks, which were easier to locate than eggs, were sometimes found in burrows where no egg had been recorded (Serventy & Curry 1984).

The preliminary results show that for consecutive, repeated burrowscope checks of the same nest sample performed over two weeks of the egg stage, researchers missed up to 34% of nests. Another source of burrowscoping error was recording the same nest more than once from different burrow entrances. It is usually difficult to tell the exact direction underground the burrowscope is being manoeuvred, and therefore to ascertain whether the same nest site is being repeatedly recorded. The third consecutive check at Snares C gave a much higher proportion of correctly recorded nests, but the number of repeat recordings of the same nest from more than one entrance was also higher. Although researchers attempted to put the same amount of time and effort into each burrowscoping check, effort may have varied, particularly relative to how cold, wet and uncomfortable conditions were for researchers at the time. Likewise, although researchers attempted to treat each consecutive check independently to avoid bias from prior knowledge of occupied burrows and nest locations, some bias was inevitable. This may partly explain why the third consecutive check was the most successful in correctly finding nests.

Accuracy of burrowscoping in detecting nest (i.e. egg) number

Ninety-one nests were discovered when Snares C was excavated and only 50% of these had been correctly recorded on each of three consecutive burrowscope checks. The most accurate burrowscope check recorded only 80% of the nests present. The proportion of missed nests using the burrowscope is probably affected by the complexity of the burrow system and the number of connections between burrows which are relative to soil structure and the presence/absence of trees in the site.

Preliminary surveys for Whenua Hou B and Snares A indicate that complexity of Sooty Shearwater burrow systems is not unique to the Snares C plot and burrowscoping inaccuracy could occur elsewhere. Data from observation holes at Snares A showed that during the young chick check, 11% of nests were missed by burrowscoping and during the pre-fledging chick check, 17% of nests were missed. An understanding of the representativeness of the above results is needed before continuing to use the burrowscope to determine burrow occupancy in the Sooty Shearwater research programme.

Sampling required to better estimate accuracy

This pilot study has indicated a high level of imprecision and inaccuracy in burrowscope detection of Sooty Shearwater eggs and chicks. It is proposed that the excavation experiment be repeated and replicated on other study islands in order to quantify the burrowscope error in determining burrow occupancy. Current estimates of spatial variation in accuracy are too crude to estimate the sample sizes required to measure accuracy with sufficient statistical power (Hamilton *et al.* 1998). However, large numbers of replicated plots on a number of islands and at several stages of the breeding season would require considerable effort and an undesirable level of disturbance. To minimise disturbance, I suggest excavated plot sizes of 5 m × 5 m which, based on prior experience, would take *c.* 4–5 person-days to assess. It is hoped that with additional excavated plots on a number of study sites, a correction factor can be developed for the proportion of nests that the burrowscope misses.

This pilot study gives grounds for optimism that disrupted experimental areas will be rapidly recolonised by Sooty Shearwaters. The amount of activity that was observed at Snares C a month post-excavation was notable, especially as at least 36% of the original adults were still present. However, recolonisation of different areas may be affected by the local Sooty Shearwater population size and density. The Sooty Shearwater population on The Snares is large (estimated 2.75 million breeding pairs, Warham & Wilson 1982) which may mean there is a high proportion of breeding-age adults restricted by competition for burrows and nesting space who will quickly recolonise a disturbed area.

Research investigating burrowscoping accuracy can concurrently address different questions using the same data. For example, studying variation in the recolonisation rates of excavated areas between sites may reveal density-dependence effects which, if present, has implications for the predictions of harvesting impacts. Experimentation with and without 'starter' entrance holes and different filling-in regimes may also reveal valuable lessons on how to facilitate colony restoration. Repetition of plot excavations in other areas should incorporate a follow-up programme to monitor the rates of recolonisation.

CONCLUSIONS

The extreme complexity of the burrow systems excavated at The Snares forces re-evaluation of the definition of 'burrow', the meaning and value of measuring entrance abundance, and the concept of 'burrow occupancy' for the Sooty Shearwater research programme. If subsequent research reveals similar levels of complexity elsewhere, the 'burrow occupancy' concept may be abandoned for a direct measure of the number of eggs or chicks per unit ground area.

It may be that the high density of Sooty Shearwaters on The Snares, along with the soil structure and presence of trees, has caused extreme complexity in burrow geometry. Whereas burrowscoping may be unusable there, it may still be useful at other study sites or for studies of other species. However, this study signals the potential need for careful assessment of burrowscoping data in research programmes, particularly for endangered burrow-nesting seabirds (e.g. Chatham Island Taiko *Pterodroma magenta*, Hutton's Shearwater *Puffinus huttoni*). A variety of burrowscopes (infra-red and fibre-optic) is being used around the world for studies on other bird species (Dyer & Hill 1991, Purcell 1997). Checks of the accuracy and precision of the results obtained from burrowscopes in other studies are valuable and highly recommended.

ACKNOWLEDGEMENTS

Financial support was received through a Foundation for Research, Science and Technology (FRST) grant to the Rakiura Titi Committee for the *Kia Mau Te Titi Mo Ake Tonu Atu* Research Programme, administered by the University of Otago. Funding was also received from the Department of Conservation. I would like to thank Christine Hunter, Nic Alterio, Keryn Squires, Matt Charteris, Tina de Cruz, Gen Taylor, Joe Hayes, Ray Guse and Martin Renner for their invaluable help with field work on The Snares and Whenua Hou. Thanks to Murray McKenzie, Ian Dickson and Matthew Dooher for constructing the burrowscopes, Ken Miller for drawing Figure 1, and David Fletcher for statistical advice and discussion. Tina de Cruz, Henrik Moller and Christine Hunter provided useful and helpful comments on earlier drafts of this manuscript.

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