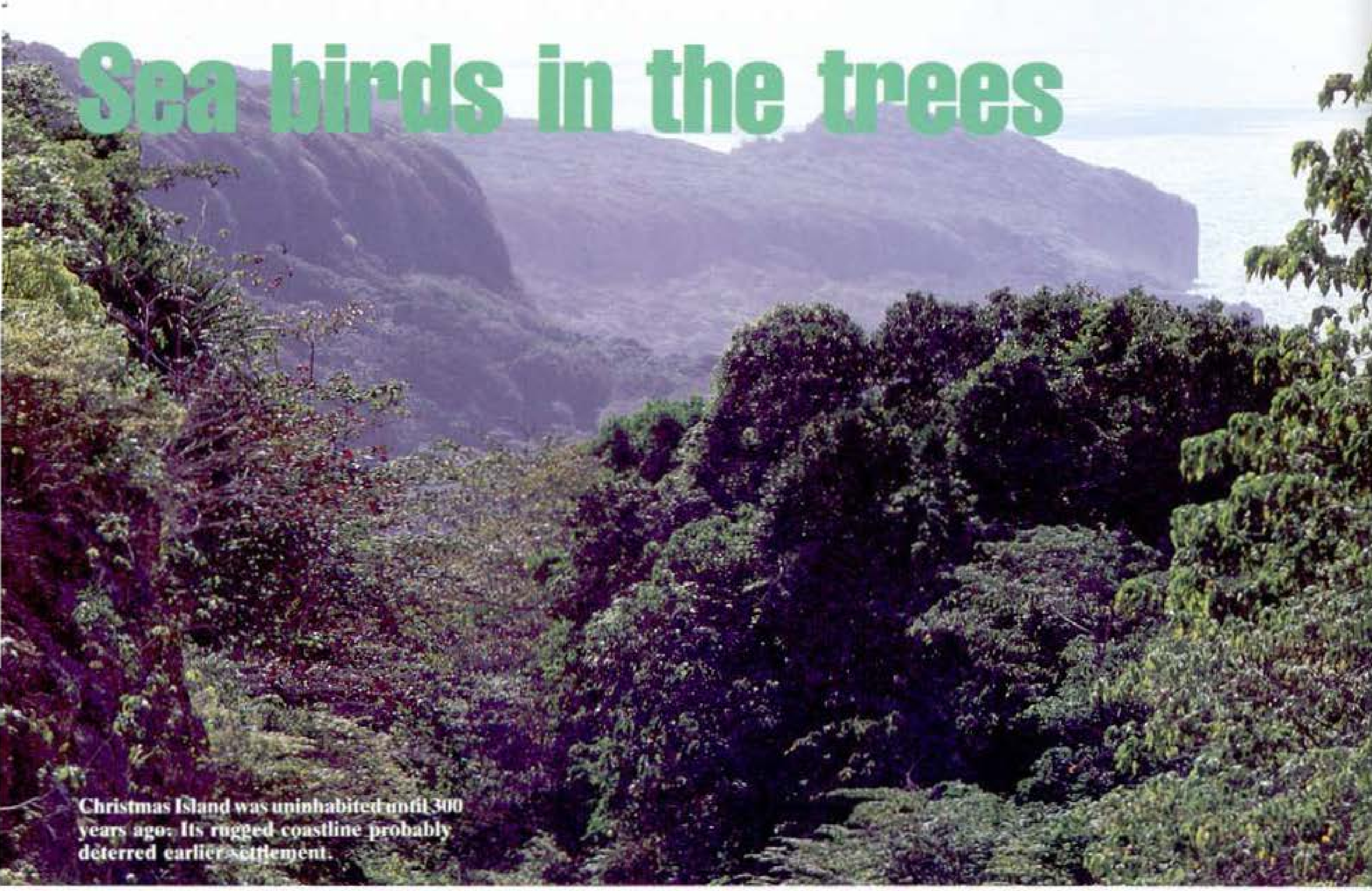
Sea birds in the trees



Christmas Island was uninhabited until 300 years ago. Its rugged coastline probably deterred earlier settlement.

On the eastern side of the Indian Ocean, about 350 km south of Java and 1400 km north-west of Port Hedland, lies an isolated Australian territory — Christmas Island.

To the visiting mariners who first clambered up its palm-strewn cliffs some 300 years ago this little tropical isle must have inspired both awe and delight. No doubt it was their tales of islands like this that spawned generations of childhood fantasies, replete with shipwrecks, pirates, and unseen creatures whose eerie plaintive calls would echo through dense jungle-covered hills swathed in mist.

Perhaps Christmas Island does have chests of pirate gold hidden in its damp limestone caves, but a different sort of treasure brought settlement to its shores in 1888 — rock phosphate. Beneath the rainforest, lodged between pinnacles of limestone, the phosphate deposited five million years ago as guano has provided Australians in the 1980s with about one-quarter of our annual demand for the mineral. But extracting the phosphate has not been without some environmental cost.

The extent of that cost is now being determined by scientists from the Australian National Parks and Wildlife Service (ANPWS), who are responsible for managing a large part of the island designated as national park. For one of their benchmarks, they are measuring the way in which mining has altered the habitat, and hence the viability, of a sea bird unique to the island — the abbott's booby (*Sula abbotti*).

An unusual biota

Like the finches of Galapagos that so inspired Charles Darwin, the isolated fauna of Christmas Island have evolved some unusual traits, influenced by the island's seasonal climatic extremes. Although mean daily minimum and maximum temperatures hover between a pleasant 20 and 30°C all through the year, seasons are marked by the absence or presence of rain: from May to September the south-east trade winds bring little or none, while most of the annual rainfall of about 2000 mm falls between December and April in stormy, heavy downpours, usually associated with cyclonic depressions.

The onset of the wet season is heralded by the famous migration of the island's millions of red crabs (*Gecarcoidea natalis*). When they are not moving to or from the sea, the crabs lord it on the forest floor, feeding on leaves, berries, carrion, and any living animal small enough to eat. Over millennia their aggressive activities have probably had a significant influence on the composition of the island's vegetation and crabs are more than likely responsible for the absence of small ground-nesting birds.

In stark contrast to the marauding red crabs; 20 metres above in the branches of the rainforest trees nests the abbott's booby. While the female crab abrogates her parental responsibility when she has laid her eggs, and uses a breeding strategy that relies on the production of thousands of young moving together and overwhelming the gastronomic capacity of predators, the abbott's booby lays a solitary egg and the male and female nurture the chick for more than a year (see the box on page 6).

Biologists consider that this low level of fecundity leaves the species highly susceptible to changes in its habitat. In fact, it has already been eliminated from its central and western Indian Ocean nesting grounds, leaving Christmas Island the sole remaining breeding place.

So when in 1966 Mr A. J. Pearson, a British ornithologist, suggested that probably only 100 pairs remained, the Interna-

The abbott's booby is the rarest and most restricted in distribution of the species belonging to the sea-bird family Sulidae (gannets and boobies).

tional Union for Conservation of Nature (IUCN) listed the abbott's booby in its Red Data Book as an endangered species. A short time later, another biologist, Dr Bryan Nelson of Aberdeen University, took advantage of a mining survey grid that gave him easy access to the booby's major breeding sites to study the bird and make another assessment. His upward revision of the estimated number of breeding pairs allayed fears about the species' immediate survival. But on this visit, and a subsequent one in 1974, he expressed considerable concern about the extent to which the mining operations were clearing forest that the abbott's booby uses for nesting.

Over the next decade, various biologists concerned about the future of the species pointed to the need for a long-term co-ordinated program that would monitor the effects of mining on its breeding success. Finally, July 1983 saw the start of an Abbott's Booby Monitoring Program, jointly funded for 6 years by the ANPWS and the Phosphate Mining Company of Christmas Island and staffed by Dr Barry Reville, Mr Jeff Tranter, and Mr Hugh Yorkston.

Mining, forests, and nesting behaviour

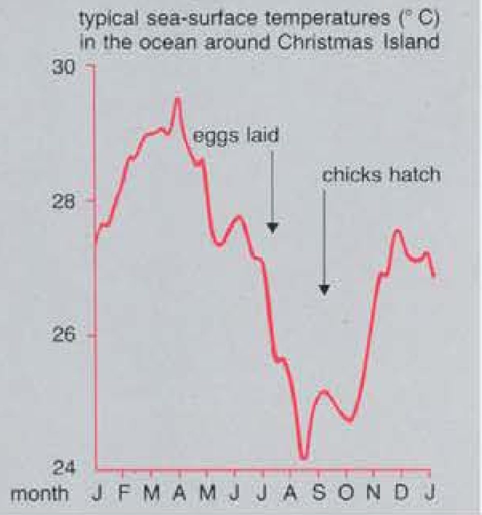
Commercial mining began slowly in 1895, and for 75 years was confined to the eastern half of the island, where few abbott's boobies nested. However, in 1970/71 the mining operation moved to the central and western areas that the bird prefers. By 1980, about one-third of its breeding habitat had been destroyed.

As part of an unusual breeding strategy, adult birds feed their only chick for more than 16 months.

Despite being true ocean birds spending months at sea, abbott's boobies need the rainforest for nesting. Their habit of building nests high in the trees is more than quaint, aberrant behaviour. It is a necessity linked to their long narrow wings, which let the birds glide great distances with only occasional flapping. This aerodynamic efficiency carries a price: the wing size and shape make it difficult for adult birds to take off from the ground. For young fledglings it is impossible.

As part of a behavioural strategy to gain the most preferred flying conditions, breeding pairs — thought by biologists to mate for life — choose to nest on thin lateral branches below the canopy of tall emergent trees. Because, like glider pilots, they need to fly into the wind to land, most nest on the north-western side of trees in parts of the island offering some shelter from the prevailing south-easterly winds. At take-off, rather like hang-glider enthusiasts leaping off the edge of a cliff, the birds sometimes drop 10 m before getting under way.

Hatching in the trough



Abbott's booby chicks that hatch when the sea-surface temperatures are lowest benefit from a greater abundance of food associated with the cold nutrient-rich water.

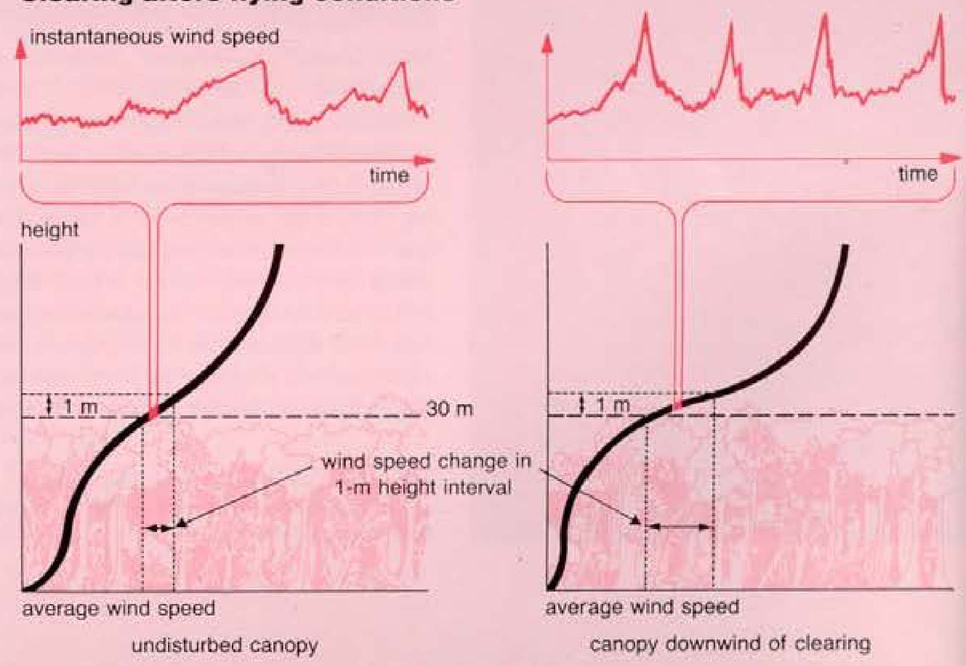
A young abbott's booby coming in to land after its first few flights has little margin for error. To survive, it must land safely in the branches near the nest on its first attempt. A missed footing sees it crashing through the branches to the forest floor, where, unless it can claw its way up creepers or shrubs to gain a little height for take-off, it is doomed to die of starvation.

Effects of forest clearing

Obviously, when trees are removed, nest sites disappear with them. But Dr Reville and his team have discovered that clearing forests has even greater ramifications. From their early observations they noted that, over a distance of about 300 m downwind of the cleared areas, many of the breeding pairs seemed to be abandoning their regular nest sites. This suggested that changes in wind pattern induced by the clearings were having a major influence on the birds' breeding success. To test their conjecture the scientists began a long-term observational study.

At the start of the Monitoring Progam, using the results of an island-wide survey of nest sites in 1980/81, Dr Reville's team made a random selection of 108 nests that were to become 'core sites' for further study. They designated these as the centres of 1·2-ha circular study blocks containing a total of about 1100 sites, which they used for general observations on the changes in

Clearing alters flying conditions



Downwind of a clearing, abbott's boobies encounter more frequent and more intense gusts than those in an undisturbed canopy. The sudden change in wind direction and strength — the 'wind-shear' phenomenon so disliked by pilots landing aircraft — makes flying conditions more difficult and causes dangerous mislandings.

Breeding strategy has links with upwelling

Removal of nesting sites apart, the abbott's booby already copes with considerable environmental challenges to rear its young. The lack of plentiful, year-round fishing commonly associated with warm tropical seas and the violent cyclonic storms that cover the island for 3 months each year have no doubt contributed to the development of the species' unusual breeding strategy.

Unlike other members of the family Sulidae (gannets and boobies), the abbott's booby does not live in large colonies but, with a mate chosen for life, nests alone in the branches of emergent rainforest trees. That the bird lays only a solitary egg is unusual in itself; stranger still is the slow growth rate of the young chick and the length of time that it is nurtured by its parents.

Studies of the birds' breeding behaviour by biologists Dr Bryan Nelson and Mr David Powell show that, typically, parents incubate the egg for about 57 days and feed the fledgling for 151 days. Then follows a further post-fledging feeding of 230 days. Adding to these times an average 66 days of pre-laying activities, such as nest-building, gives a breeding cycle of about 504 days, or more than 16 months.

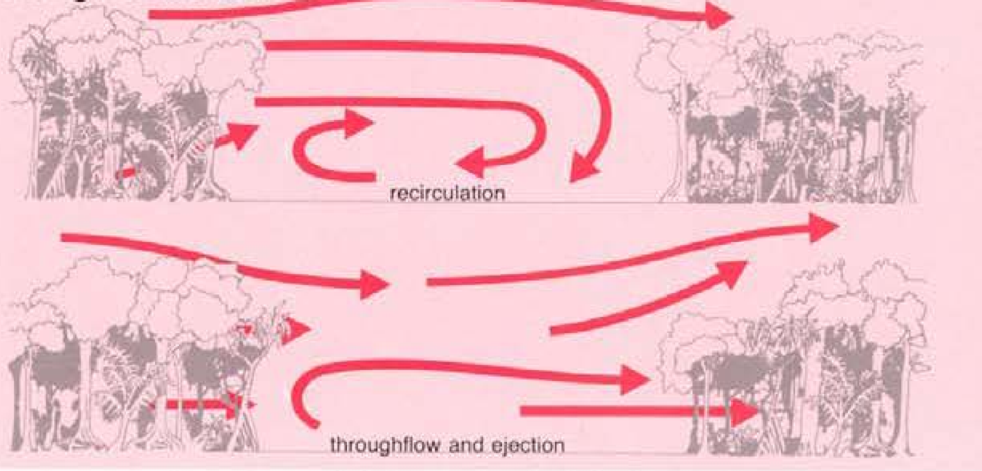
This unusual biennial approach to breeding appears to be strongly linked to an upwelling of cold water between Java and Australia. When, in 1961, Dr K. Wyrtki from CSIRO's Division of Fisheries and Oceanography described the upwelling, following cruises on the H.M.A.S 'Diamantina', little was known about the biology of the abbott's booby. Although Dr Wyrtki was aware of the biological importance of nutrient-rich currents — he took measurements of the levels of inorganic phosphate as well as temperatures at various depths — nobody knew that the abbott's booby's breeding behaviour was so closely linked to this annual phenomenon.

Observations made by the abbott's booby monitoring team suggest that timing of hatching is critical to breeding success. According to Dr Reville and his colleagues, who have compared the timing with sea-surface temperatures measured by the National Oceanic and Atmospheric Administration (U.S.A.) satellites, parents rearing late-hatched chicks encounter rising water temperatures and poorer fishing. They thus cannot adequately feed the chick, which usually dies.

Apparently, the optimum strategy for a breeding pair is for the chick to hatch in September, when the upwelling is most prominent and food plentiful. By the onset of the cyclone season, the young chick is strong enough to face the lean months between December and April, when it may actually lose weight because food is scarce. At the beginning of the dry season when food supply improves, if the chick has not starved to death it continues to be fed by its parents and slowly regains weight until it is strong enough to become independent. Independence occurs between July and September, the beginning of the annual upwelling and a period of highest food availability.

The upwelling in the region between Java and Australia during the south-east monsoon. K. Wyrtki. *Australian Journal of Marine and Freshwater Research*, 1961, **13**, 217–25.

How gusts are made



Gusts appear downwind of the clearing when the air suddenly stops recirculating and is ejected into the flow at canopy height.

nesting density. They also used the core sites and their four nearest neighbours as the foci of more detailed studies.

The scientists classified each study block as belonging to one of three categories determined by the exposure to the prevailing south-easterly wind: 'upwind' (within 305 m to the south-east of a clearing); 'downwind' (within 305 m to the north-west); and 'beyond' (further than 305 m from any clearing). They chose 305 m as equivalent to ten times average canopy height, which they considered to be the likely boundary of wind changes caused by the clearings.

Each fortnight from April 1984, the team estimated wind-caused canopy movement in the region of the nest on a four-part scale, where 1, 2, 3, and 4 represented movements of nil, 0·5 m, 0·5–1 m, and greater than 1 m respectively. Among other observations, every 3 months they monitored breeding activity in each study block.

After analysing the data from more than 3 years of study, the scientists have found a definite link between unsuccessful breeding and wind turbulence downwind of the forest clearings. The 'downwind' blocks contained a greater proportion of sites with large canopy movement, more adult pairs moved nest sites there, and significantly fewer chicks survived than in the 'upwind' blocks.

By the beginning of 1987, Dr Reville's team considered that the breeding population was steadily declining, a trend that they attributed largely to changes in the wind pattern downwind of the forest clearings that were significantly disrupting the breeding success of the birds. To provide an aerodynamic explanation of these wind disturbances — information that would assist in the design of future management and amelioration strategies — in April of that year the ANPWS sought the help of CSIRO's Centre for Environmental Mechanics, which has a core research program examining the characteristics of wind.

The wind and the forests

Although the Centre's Dr Michael Raupach and his colleagues, Dr Frank Bradley and Dr Hossein Ghadiri, were studying how wind moves through and interacts with forest crowns — part of a larger program looking at flow patterns in vegetation canopies, over hills, and around shelter-belts — they had not examined the specific problem of turbulence associated with forest clearings.

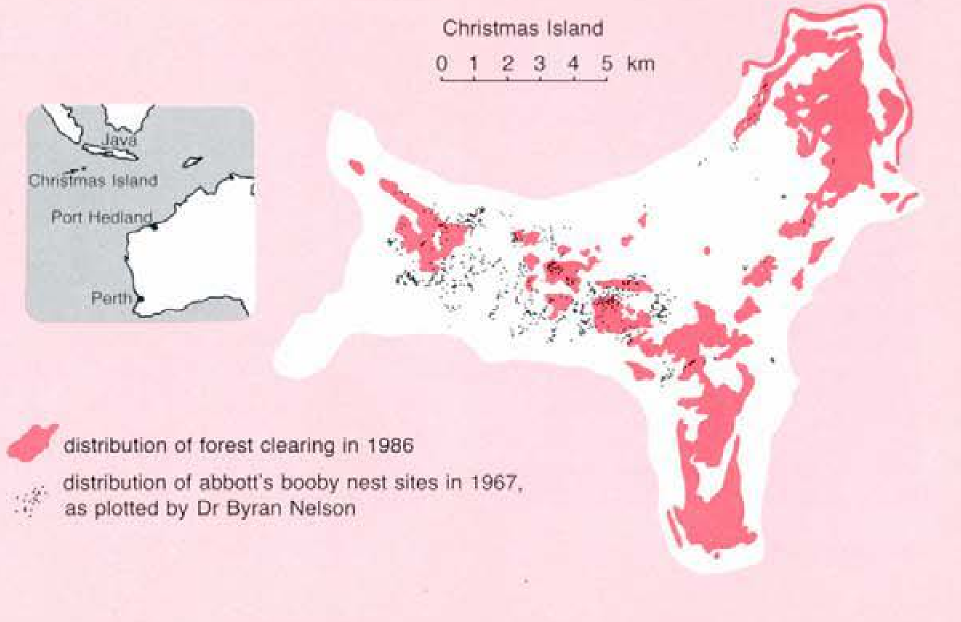
But from their knowledge of wind behaviour the scientists knew that, within and downwind of cavities in solid surfaces, they could expect to see clear, systematic recirculating vortices. If the top of the rainforest was essentially equivalent to a solid surface, this pattern of wind disturbance would occur in and downwind of the clearings in the forest, and an aerodynamic explanation for changes in wind pattern could be given immediately.

However, a search of the literature on the way wind flows in and around gaps in the forest showed that the analogy between a forest clearing and a solid cavity was tenuous. Previous research suggested that passage of the wind through the upwind and downwind edges of the clearing causes a difference in the resulting flow. To clarify the matter Dr Raupach recommended to the ANPWS that a short wind-tunnel study be undertaken. Tower-based turbulence measurements above the 40 m forest on the island would have cost tens of thousands of dollars, whereas wind-tunnel simulation — repeatedly verified as accurately reproducing the behaviour of the real atmosphere — can be done for a small fraction of the cost. The Service agreed to his recommendation and contracted the Centre for Environmental Mechanics' to undertake the work.

After constructing a model of the forest in the wind tunnel and ensuring that it reproduced the scale, density, and roughness of the real forest canopy and the clearings, Dr Raupach and his colleagues began their experimental program by using smoke to trace flow patterns. Their examination of video pictures of the smoke for a range of clearing lengths and wind speeds showed the absence of any systematic recirculating vortex, such as occurs in the solid-cavity model, either within or downwind of the clearing. Instead, in both locations, intermittent vortices were successively formed and ejected into the flow.

To find out more about the properties of this turbulence they carried out a series of wind-velocity measurements in the tunnel with very small, rapidly responding sensors that could measure the average wind speed and the turbulent fluctuations. These measurements revealed a well-defined zone in the canopy, downwind of the clearing, in which the turbulence is unusually violent.

Forest clearing and nest sites



The original map was prepared by ANPWS.

Bringing rainforest back to these clearings will be a difficult task.

Dr Raupach's team called this an 'enhanced gust zone'. It extends horizontally from three to seven canopy heights downwind of the edge of the canopy and vertically through the top 40%. Within this zone, although the mean wind levels don't differ much from those in an undisturbed forest, the nature of the turbulence is very different. It is a lot more gusty.

These gusts would make flying and landing in the branches of the forest canopy much more precarious, particularly for inexperienced fledglings. However, without continuous observation of nests — not a practical proposition for hundreds of nests 30 m up in the rainforest canopy — the ANPWS scientists cannot be certain what percentage of chicks fall to the ground during vigorous canopy movement through dislodgement from nests or by 'mislanding', although they report that they have witnessed the latter.

The wind-tunnel work also showed that the intensity of the turbulence varies with the size of clearing. The enhanced gust zone reaches its full intensity when the clearing is ten or more canopy heights in length.

Future management

Now that they have a better understanding of the wind turbulence problem and its impact on the abbott's booby, officers of the ANPWS are developing amelioration strategies for the birds' breeding grounds. These strategies will be incorporated into broader management plans the Service is developing for other parts of the island designated as national park.

In December 1987, the Australian government stopped phosphate-mining with the announcement of an extension to the park and an end to further forest clearing. Since then, the government has invited private companies to tender for the rights to mine the areas already cleared, with the proviso that a part of the royalty would go towards financing the rehabilitation of cleared areas.

Recently, so that all the important ecosystems could be given the protection of park legislation, the ANPWS recommended that the area designated as national park should be extended to cover about two-thirds of the island. If this goes ahead, all the major breeding areas of the abbott's booby would come under ANPWS control.

Nevertheless, there remains the immediate problem of finding the quickest way to ameliorate the adverse impact of clearing. Time is not on the birds' side. The Monitoring Program has shown that an unsuccessful breeding pair will probably move to another site and try again. But, because the pairs tend not to move far, they may suffer several unsuccessful breeding attempts before escaping the influence of the enhanced gust zones. To compound the problem, birds moving to new sites are faced with disputes induced by overcrowding.

Obviously, the best strategy for the park managers is to eliminate the turbulence that affects breeding success so that birds can continue to nest in the areas immediately downwind of the clearings, and make a move largely unnecessary.

Eliminating the turbulence is a challenging amelioration task. Ideally, the ANPWS would like to establish an endemic, climax rainforest in the clearings, particularly as the areas are in national parks. But, going on the present poor rate of recolonisation by native plants, these clearings will take at least a hundred years before they return to forest similar to the original and before the wind turbulence is ameliorated. It's doubtful whether the abbott's booby population could wait that long. Because of the urgency, the ANPWS is exploring other options, one of which comes out of the results of Dr Raupach's wind-tunnel experiments.

These experiments showed that the best way to reduce the intensity of the gusts would be to increase the roughness of the clearings. They suggested that this could be done by planting belts of fast-growing trees at right angles to the prevailing wind, along the tops of small ridges. Selecting species that grow 2–3 metres per year could improve things greatly in about 10 years.

The ANPWS is considering an extension of this approach, which would use fast-growing exotic species planted in conjunction with native vegetation. In this way, the exotics would quickly reduce the turbulence while simultaneously improving the microclimate for the native species. In time, the exotics could be eliminated.

Clearing the trees and topsoil exposes the rock phosphate.

At this stage, alternatives are still being considered, but the ANPWS is keen to start soon on the revegetation program. As the population of abbott's boobies slowly declines, every year casts further doubt on their long-term viability.

David Brett

More about the topic

Impact of forest clearing on the endangered seabird, *Sula abbotti*. B.J. Reville, J.D. Tranter, and H. D. Yorkston. *Biological Conservation*, 1989, **48** (in press).

Monitoring the endangered abbott's booby on Christmas Island 1983–1986. B.J. Reville, J.D. Tranter, and H. D. Yorkston. *Australian National Parks and Wildlife Service, Occasional Paper* No. 11, 1987.

The breeding ecology of abbott's booby, *Sula abbotti*. J.B. Nelson and D. Powell. *Emu*, 1986, **86**, 33–46.

'Christmas Island — Naturally. The Natural History of an Isolated Oceanic Island: the Australian Territory of Christmas Island, Indian Ocean.' H.S. Gray. (Troppan: Singapore 1981.)