

to guidelines intended to limit noise emission⁷. Our data show that for such vessels, avoidance is not a source of bias.

We also deployed *Autosub-1* on eight fully autonomous missions. This was the first time that any AUV had operated successfully beyond the control range of a support facility. These missions provided over 76 h (420 km) of additional survey data which, also for the first time, span the whole water column (Fig. 1c).

AUV technology is now sufficiently robust for effective fish-stock monitoring⁹, and could advance fisheries surveys by allowing acoustic detection closer to the target species. This could improve the assessment of groundfish, such as cod, and deep-water fish, and may also facilitate more extensive high-frequency zooplankton studies¹⁰. Reductions in battery costs and improvements in the acoustic identification of species using multifrequency¹¹ and broadband¹² techniques may eventually enable AUVs to replace research vessels as acoustic sampling platforms.

Autosub-1's unique capabilities are being used in a variety of other marine-science programmes¹³, from studies of ocean turbulence to marine geochemistry. We plan to exploit the vehicle's ability further to operate in otherwise impenetrable environments later this year, when we will deploy it under Southern Ocean sea-ice to measure ice thickness, and the abundance and distribution of Antarctic krill.

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Evolution

Migration and speciation

Although migration is a common behaviour, the effects of this annual two-way event on the speciation process are poorly understood, even though birds, which are commonly migratory, played a critical role in the development of speciation theory^{1,2}. Here I propose that new developments^{3,4} in the theory of sympatric speciation — a process whereby new species can arise through population differentiation without spatial isolation — may help to explain the bursts of speciation observed in some seasonal migrant lineages.

Seasonal migrants, particularly those travelling long distances, have few recognized limits to their ability to disperse into new environments^{5,6}. These colonizations can foster the production of new species flocks — examples include nearctic *Catharus* thrushes (Fig. 1), some palaeartic *Phylloscopus* warblers, and the irruptive migrant specialists red crossbills (*Loxia "curvirostra"*)^{7–9}. I suggest that migration itself can be viewed as a key innovation that occasionally enables lineages to radiate in new environments.

Migration is a complex mode of dispersal, promoting the colonization of new areas, but also their regular re-colonization and gene flow. Spatial segregation — the linchpin of most speciation theory — becomes less and less likely with increasing migratory tendencies. Achieving true geographic isolation from other populations, thereby allowing differentiation to occur in the absence of gene flow, seems particularly unlikely among long-distance migrants, whose movements regularly encompass entire continents and oceans.

But here we have a conundrum: while migration opens the door to differentiation in new ecological and geographic space, it apparently slams it shut again through denial of geographic isolation and the promotion of gene flow.

Until now, migration was considered to counter differentiation¹⁰. Scenarios proposed to explain migrant speciation have had to invoke geographic isolation and, by implication, mechanisms such as lower historic levels of migration and greater levels of natal philopatry — neither of which fits the evidence^{11–13}. Although it is true that the origins and losses of migration have occurred independently in many lineages, it is unrealistic to suggest that the associated complex life-history characteristics were somehow held in temporary abeyance across entire lineages or clades.

Recent developments in speciation theory^{3,4} offer a theoretical framework to escape such ill-fitting scenarios, and species flocks of migrants could provide a testing ground for these theories. Phenotypic evidence in

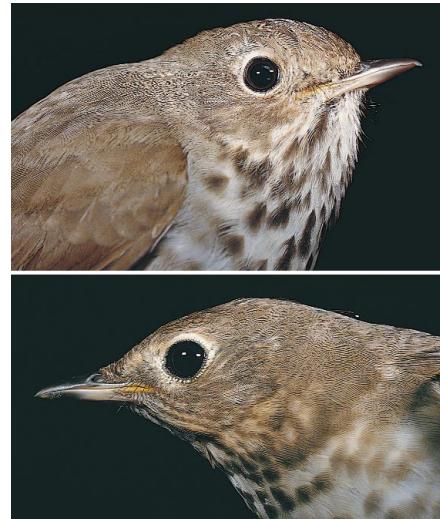


Figure 1 Hermit thrush (*Catharus guttatus*; top) and Swainson's thrush (*C. ustulatus*; bottom), two neartic-neotropic migrants from a highly migratory clade. These two species and three close relatives comprise a group of neotropical origin. They have trans-continental breeding distributions in temperate- and high-latitude neartic forests, and wintering distributions centred on neotropical North and South America.

birds suggests that sexual selection may operate only as a distant second to resource competition and perhaps reinforcement (adaptations to prevent hybridization) in driving speciation events among many migratory animals.

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Correction

Arsenic poisoning in the Ganges delta

T. R. Chowdhury *et al.*; reply from J.M. McArthur *Nature* **401**, 545–547 (1999)

The form of citation of one of the references given in this exchange (ref. 10 of Chowdhury *et al.*, ref. 6 of McArthur) was misleading and should have been written as "British Geological Survey/Mott MacDonald Ltd *Groundwater Studies for Arsenic Contamination in Bangladesh* (1999)." This is because it is the final report of *Phase 1: Rapid Investigation Phase*, not of the overall project, for which the final report will appear in 2000.