northward and shoreward off Washington where it quickly loses its identity in the flood of fresh water from swollen coastal streams and winter rains. How far north the plume extends or how deep it mixes under these conditions have been problems beyond solution by the classical tools of oceanography (*8*). Radiochemical techniques should help resolve these uncertainties (*9*).

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References and Notes

1. This is the number usually reported by Hanford Laboratories, but some reduction should have occurred during the first 6 months of 1965, when phasing out of three of the eight reactors began.
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6. The coprecipitation techniques used are well known to chemists. We checked our methods both in the laboratory and at sea to give maximum recovery of Cr^{51}, but yields for the other radioelements were not determined.
7. The estimate of speed depends on a constant rate of delivery of Cr^{51} to the ocean. Probably changes in reactor output occur, but hopefully they are minimized by mixing in the river and in the three lakes through which the Cr^{51} must pass on its 530-km trip to the sea.
8. K. Park, in our laboratory, has a paper in press, *Limnol.* and *Oceanog.*, in which specific alkalinity is used to identify Columbia River water at sea.
9. Supported by AEC contract AT(45-1)1750 and PHS training grant 1T1-WP-59-01. We thank the U.S. Coast Guard for making the *Modoc* available to us and L. Frederick and W. Vermeere for assistance with the sampling program.

23 September 1965

Avifauna: Turnover on Islands

Abstract. *The percentage of endemic species of birds on islands increases with island area at a double logarithmic rate. This relation is apparently due to extinction, which is more rapid the smaller the island. The turnover resulting from extinction and replacement appears to be far more rapid than hitherto suspected.*

Extinction is perhaps the most elusive of all evolutionary phenomena. What little we know about it has been contributed by paleontologists and biogeographers. In the case of "many . . . extinctions . . . there are no visible causes for the sudden disappearance of a form, except that the total size of the population was so small and genetic composition probably so uniform that the most minute change of environmental conditions became fatal. There is little doubt that . . . well isolated islands are evolutionary traps, which in due time kill one species after another that settles on them" (*1*). If size of the population is the crucial factor, it should follow that the rate of extinction should be the more rapid the smaller the island. A further expected consequence is that the smaller the island the lower the percentage of endemic species should be, because most of the populations become extinct before they reach species level, or soon thereafter. MacArthur and Wilson (*2*), on the basis of slightly different considerations, arrived at a similar conclusion.

It is only rarely recognized how much smaller than one might expect is the percentage of endemics among birds as the result of extinction, even on relatively large and old islands. New Caledonia, an island going back to the Mesozoic, has only one old avian endemic, the kagu *Rhynochetos jubatus* (*3*). Fleming (*4*) has similarly shown in a very original analysis that about three-quarters of the land birds of New Zealand are recent immigrants.

The relationship between island size and percentage of endemics appears to be far more regular, at least among birds, than previously recognized. In Figs. 1 and 2 the logarithm of island area is plotted against the logarithm of the percentage of endemic species of land birds. The relative goodness of fit can be seen from the graphs. These graphs must be considered as mere approximations, for the exact number of the resident, breeding, land-bird fauna is not certain for some of these islands, and in many cases an arbitrary decision must be made whether to call an endemic isolate a species or a subspecies.

The curve for each type of island has a different zero point, but the slope is the same for the four kinds of islands shown. Solitary, well-isolated islands (Fig. 1, curve A) show only small deviations from expectancy. Manus and Socotra (Fig. 1, curve B, points 9 and 10) have a higher than expected endemicity; both are far enough from the nearest mainland or archipelago so that they are somewhat intermediate between islands shown in curves A and B. In the case of islands in scattered archipelagos (Fig. 2) most major deviations—for example, Kauai, Viti Levu, and Jamaica (points 8, 11, and 12)—can be explained in terms of relative isolation. The relation shown in Figs. 1 and 2 does not hold true for islands that are members of tight archipelagos (Solomon Islands, Bismarck Archipelago, Moluccas) or, of course, for islands in the temperate zone which had a complete faunal turnover during the Pleistocene.

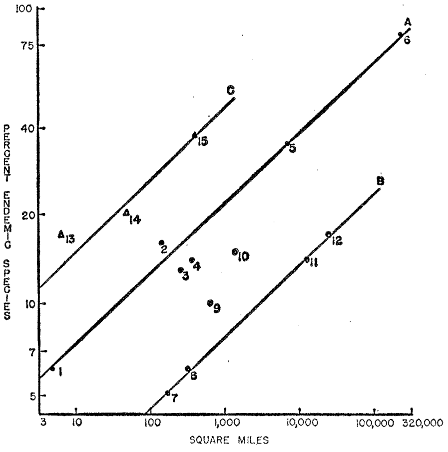

Fig. 1. Double logarithmic plottings of area against percentage of endemic species of birds on three kinds of islands. (*A*) Solitary, well-isolated islands: Lord Howe, 1; Ponape, 2; Rennell, 3; Chatham, 4; New Caledonia, 5; Madagascar, 6. (*B*) Single islands near mainlands or large archipelagos: St. Matthias, 7; Pemba, 8; Manus, 9; Socotra, 10; Timor, 11; Tasmania, 12. (C) Islands in the Gulf of Guinea: Annobon, 13; Principe, 14; San Tomé, 15.

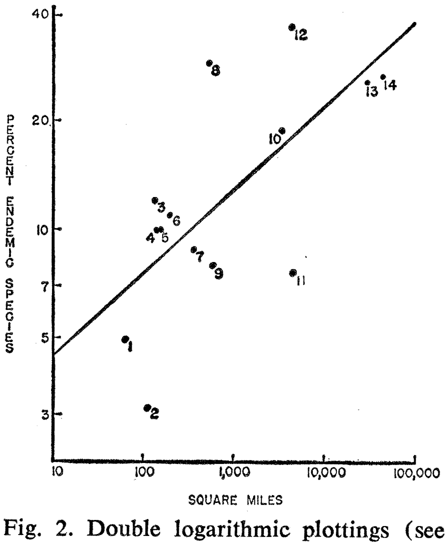

Fig. 2. Double logarithmic plottings (see Fig. 1) for islands in scattered archipelagos: Vanikoro, 1; Moheli, 2; Mayotte, 3; Anjouan, 4; Kandavu, 5; Santa Cruz, 6; Grand Comoro, 7; Kauai, 8; Oahu, 9; Puerto Rico, 10; Viti Levu, 11; Jamaica, 12; Hispaniola, 13; Cuba, 14.

The more stable the environment, apparently, the slower the turnover, other things being equal.

The most important fact that emerges from this analysis is that faunal turnover on islands is far more rapid than previously recognized and that this turnover is characterisic not only for very small islands but occurs on islands of any size. Various considerations indicate that extinction is by no means necessarily caused by competition from new colonists or by new pathogens introduced by them. Rather one must assume the existence of a general vulnerability to changes which includes weather factors (hurricanes), climatic fluctuations, and biotic changes of any kind.

Birds may well be unique in the rapidity of turnover, for the rich endemic floras of New Caledonia and the Venezuelan highlands indicate a very different situation for plants and perhaps for insects associated with plants.

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12 October 1965

Isoprenoid Hydrocarbons in Recent Sediments: Presence of Pristane and Probable Absence of Phytane

Abstract. *Pristane (2,6,10,14-tetramethylpentadecane) has been isolated from two recent marine sediments. Unlike their ancient counterparts, these sediments contain no detectable phytane. These two facts suggest a biochemical origin for at least a fraction of the sedimentary pristane and a later, geochemical formation of phytane. Commercial reagent-grade solvents (pentane, isooctane, methanol) contain appreciable quantities of fossil pristane and probably phytane.*

Terpenoid hydrocarbons are among the most ubiquitous natural products. Pristane (2,6,10,14-tetramethylpentadecane), which occurs in some terrestrial plants and animals (*1*), is especially abundant in marine crustaceans (*2*) such as copepods. These copepods derive pristane from phytol in their food. As a relatively stable compound phytol passes through the marine food chain and accumulates in the fat of most marine fishes and mammals. Much interest centers around the recent discovery of pristane, phytane, and related isoprenoids in crude petroleum (*3*) and in ancient sediments (*4*), some of great antiquity. From petroleum and derived products, fossil isoprenoid hydrocarbons reenter the present-day environment.

The search for terpenoid hydrocarbons in recent marine sediments seemed of particular interest for closing one of the most extended biogeochemical cycles known. We obtained grab samples of sediment from the Wilkinson Basin, a depression in the shelf off Cape Cod, Massachusetts, and from Volden Fjord, Norway. The water column in both regions is rich in pristane-bearing Calanoid copepods. The sediments, preserved in the frozen state, were extracted first by methanol, then by methanol-benzene azeotrope. After dilution with water, the hydrocarbon-soluble fraction of the extracts was transferred to pentane. The solvents were removed at room temperature in a rotating evaporator. Silica-gel chromatography isolated the saturated hydrocarbons.

Great care was taken to reduce the contamination of the samples by fossil isoprenoids. Pristane was isolated and identified from a sample of commerical pentane (Phillips Petroleum Company, pure grade). Its concentration was 3×10^{-6} g/liter. The same contaminant occurs at lower concentration also in pure isooctane (2×10^{-7} g/liter) and reagent grade methanol (3×10^{-7} g/liter). Phytane appears to be present at comparable concentration; however, we have not isolated the corresponding chromatographic peak. Redistillation through an efficient, packed column lowered the pristane content of the solvents to 10^{-8} g/liter. Blanks carried through the entire procedure indicate that less than 3 percent of the pristane extracted from the sediments is contributed by all sources of contamination.

The hydrocarbon concentrate from the recent sediments was separated by gas chromatography on a strongly polar substrate for maximum resolution of the isoprenoids from the adjacent straight-chain hydrocarbons. The pristane and phytane regions were trapped in melting-point capillaries cooled by dry ice; etching of their internal surface and packing with steel wool to increase the condensation surface made the recovery quantitative.

The trapped pristane and "phytane" fractions were chromatographed again on a nonpolar column; infrared spectra of the pristane fractions were obtained with sampling equipment suitable for very small quantities. The retention indices on both gas chromatography columns together with the fine structure of the methyl-deformation band at 1370 cm^{-1} (Table 2) conclusively prove the presence of pristane. In both samples the pristane content (Table 2) is only slightly below that of the adjacent straight-chain hydrocarbons. On the nonpolar column, the sample collected in the phytane region off the polar column resolved into four major and several minor peaks; none had the retention index of phytane. We estimated that phytane would have been detected if it amounted to as little as 3 percent of the pristane.

Unlike ancient sediments these two recent pristane-bearing deposits con-

Table 1. Identification of pristane. Gas chromatograms, temperature programmed at 4°C/min; 1.8 m by 0.3 cm steel columns; 1.6 percent Apiezon L on Chromosorb G, acid-washed, dichlorodimethylsilane-treated; 3.5 percent RTV 502 (filler free) (Dow Corning) on the same substrate; 25 percent FFAP (Wilkens Instrument, Inc., Walnut Creek, Calif.) on Chromosorb W, acid-washed, trimethylchlorosilane-treated.

Retention index			Maxima of infrared spectra (cm^{-1})		
Apiezon L	RTV 502	FFAP			
		Pristane			
16.92	17.12	16.64	1360	1375	1382
		Phytane			
	18.15	17.73			
		Pristane (Wilkinson Basin)			
16.90		16.64	1360	1375	1382
		Pristane (Volden Fjord)			
	17.12	16.64	1360	1375	1382
		Phytane-fraction (Wilkinson Basin and Volden Fjord)			
	17.00	17.72			
	17.38				
	17.77				
	18.27				