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TICK DISTRIBUTION IN THE CENTRAL PACIFIC AS INFLUENCED BY SEA BIRD MOVEMENT[1, 2]

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Abstract: Tick distribution in the Central Pacific region reflects the influence of 2 distinct sea bird breeding populations — northern, Hawaiian Is. area, and southern, Line Is.-Phoenix Is. area. Four tick species — *Ixodes amersoni, I. layssanensis, Ornithodoros desmarki,* and *O. capensis* — are associated with birds nesting on Central Pacific islands. *I. amersoni* is known from Phoenix I. and Enderbury I., although in time it probably will be found on other islands of the southern Central Pacific area as well. *I. layssanensis* and *O. desmarki* are presently known from certain islands in the northern Central Pacific area, but these also are expected to be found eventually on all of the islands in this area as well. *O. capensis* is widely distributed throughout tropical and subtropical oceans, including the entire Central Pacific region; it is suggested that sea birds may have brought this species to both northern and southern Pacific areas from other parts of the world. It is further suggested that the *O. capensis* population in the northern Central Pacific area does not normally mix with the southern Central Pacific population, due to the limited sea bird movement between these 2 areas. Although the tick-dissemination potential of sea birds which migrate annually into and through the Central Pacific is great, tick deposition is minimized, since these birds normally remain at sea during their nonbreeding periods and seldom stop on islands.

The role of land birds in transporting ticks and other parasitic arthropods has recently been studied by Hoogstraal et al. (1961, 1964), Nuorteva & Hoogstraal (1963), Pavlov (1964), Semashko (1959), and Vshivkov (1956). These studies show that birds do transport ticks over varying distances and that in some cases birds do account for the distribution of ticks.

The role of sea birds in transporting ticks is rather poorly known since (1) many sea birds breed over wide ranges; (2) their breeding grounds are often on isolated and seldom-visited islands; (3) the migration routes of many are unknown; and (4) in some instances their postbreeding grounds are either poorly understood or completely unknown. Furthermore, the distribution of sea bird ticks is also poorly understood. This deficiency is due mainly to a lack of collection over the ranges of the various hosts.

Schulze (1938) and Zumpt (1952) suggest that sea birds have influenced the distribution of *Ixodes uriae.* This species is known from the Arctic and sub-Antarctic areas, and Schulze has called it a "bipolarly distributed" tick since it shows a circumpolar distribution in both areas. Zumpt indicates that attached ticks could be carried between the 2 regions by sea birds such as Wilson's Storm Petrel (*Oceanites oceanicus*) which breeds in the Antarctic and migrates northward to the Arctic, or the Arctic Tern (*Sterna paradisaea*) which breeds in the Arctic circumpolar region and then migrates to the southern regions. In addition, Zumpt states that dispersal may be accomplished by adherence of tick eggs to the feet of the host, and suggests that "the explanation is more likely to be an ecological than a historical one."

The Central Pacific (FIG. 1) is a unique region for studying the sea bird-tick relationship. The islands throughout this region are low-lying coral atolls characterized by low rainfall and sparse vegetation (except for the main Hawaiian Is. and a few of the Line Is. where high rainfall has created luxuriant vegetation). Until recently very little was known about the sea birds of the Central Pacific region, and similarly, very little was known about sea bird ticks in that region. In 1960 published records indicated that *Ornithodoros capensis* was known on only 11 of the 42 islands or atolls in the Central Pacific region. Only 1 other sea bird tick (an *Ixodes* species) was known to exist—and this only on 1 island.

The Smithsonian Institution is presently conducting an ecological survey in the Central Pacific Ocean which includes a study of the fauna and flora of most of the islands as well as a survey of the open ocean to determine the distribution and abundance of sea birds (Humphrey 1965). By examining the arthropod collections made by the survey through December 1966 and by correlating this with data on bird movements resulting from a banding program of the same survey, it is possible to present at this time a preliminary interpretation of the role that sea birds play in the distribution of ticks in the Central Pacific region.

To study bird movement successfully, enormous numbers of birds must be banded and subsequently recaptured. Through December 1966 U.S. Fish and Wildlife Service bands have been placed on the

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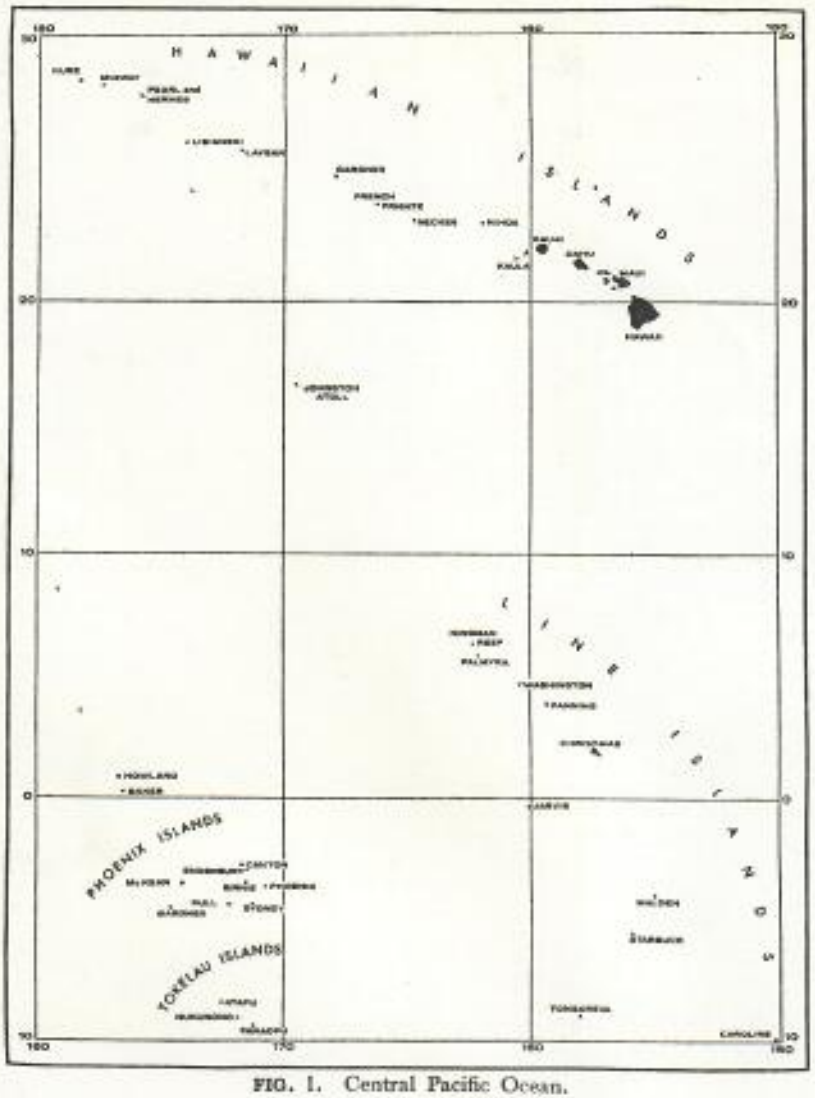

FIG. 1. Central Pacific Ocean.

legs of more than 1,350,000 birds of over 50 species. Although recaptures of banded birds number above 65,000, only a very small percentage are recaptured away from their nesting island. Nevertheless, some general distribution patterns have begun to develop from data obtained.

About 110 sea and shore bird species are known to occur in the Central Pacific. Of this number, 27 sea bird species are known to breed on islands in this region; 15 of the 27 breed throughout the region (TABLE 1), while 7 breed only in the Hawaiian Islands area and 5 breed only in the Line Is.-Phoenix Is. area (TABLE 2). Those species which breed only in 1 area do not occur on islands of the other area. In addition, 25 sea and shore bird species occur as regular migrants into or through the entire region, while the remaining 58 species are accidentals (King 1967, Clapp & Sibley 1967, Clapp & Woodward 1968).

Since 15 sea bird species breed throughout the entire Central Pacific region, one might suspect that inter-island movement of these species would be customary among all parts of the region. However, inter-island movement of nesting sea birds is not ordinarily common between certain parts of the region. Instead, 2 populations exist—northern

TABLE 1. List of sea bird species which breed over the entire Central Pacific region.

Puffinus pacificus	*Fregata minor*
Puffinus natividatus	*Sterna lunata*
Bulweria bulwerii	*Sterna fuscata*
Phaethon lepturus	*Procelsterna cerulea*
Phaethon rubricauda	*Anous stolidus*
Sula dactylatra	*Anous tenuirostris*
Sula leucogaster	*Gygis alba*
Sula sula	

TABLE 2. List of sea bird species which breed in specific areas of the Central Pacific region.

Species	Hawaiian Area	Line-Phoenix Area
Diomedea nigripes	×	—
Diomedea immutabilis	×	—
Puffinus puffinus newelli	×	—
Puffinus lherminieri	—	×
Pterodroma alba	—	×
Pterodroma phaeopygia	×	—
Pterodroma hypoleuca	×	—
Nesofregetta albigularis	—	×
Oceanodroma castro	×	—
Oceanodroma markhami	×	—
Fregata ariel	—	×
Thalasseus bergii	—	×

(Hawaiian Is., Johnston Atoll, and Wake) and southern (Line Is.-Phoenix Is., including Howland I. and Baker I.)—and the amount of movement between these 2 areas is very limited. Extensive inter-island movements of several species (namely terns and boobies) do occur within each major area and postbreeding dispersal also occurs from both areas to the Southwest, West, and Northwest Pacific Ocean. Shore birds, as transients, do move between the northern and southern areas of the Central Pacific region, but this occurs during their migration when little time is spent on islands. Thus, from the standpoint of sea bird populations, the Central Pacific region is divided into 2 major areas—the Hawaiian Is. and the Line Is.-Phoenix Is. areas.

If sea bird movement is a prime factor in the dispersal of ticks, then the present distribution of ticks and other medically important arthropods in the Central Pacific should reflect this separation in sea bird populations. To gain further information on tick distribution in this region, large numbers of hosts and their nests were examined. A total of 924 tick samples representing over 5000 specimens has been taken in 8264 arthropod collections from the Central Pacific region. These field collections have been taken from 96 host species on 43 islands and at sea.

From these collections 4 tick species—*Ixodes amersoni* and *I. laysanensis* in the family Ixodidae, and *Ornithodoros denmarki* and *O. capensis* in the family Argasidae—have been found to be associated with sea birds breeding on islands in the Central Pacific region. The distribution of the first 3 of these tick species does support evidence uncovered by bird-banding of the separation that exists between bird populations in the Hawaiian area and the Line-Phoenix area.

The first of the 4, *Ixodes amersoni*, is known only from the southern part of the Central Pacific region. It was described from 1 adult female collected from a White Tern (*Gygis alba*) at Phoenix I. on 29 May 1965 (Kohls 1966). Additional specimens have now been collected from White Terns at Phoenix I. on 15 April and 10 October 1966, and from a Red-footed Booby (*Sula sula*) at Enderbury I. on 25 September 1966. Despite an extensive search for this species on the other islands of the Phoenix group, none has been recovered. Nevertheless, this species may occur on these islands in such small numbers that it has been overlooked. If sea birds are responsible for the transfer of ticks, *I. amersoni* should also be found on the other islands in the Phoenix-Line Is. area since there is frequent movement of sea birds between these islands.

Ixodes amersoni superficially resembles *I. laysanensis;* however, the 2 species occur in separate areas. Both species also resemble *I. murreleti* which is known only from a Xantus' (Scripps') Murrelet (*Endomychura hypoleuca scrippsi*) taken on Los Coronados Island, Baja California, Mexico (Cooley & Kohls 1945).

Ixodes laysanensis has been found only in the northern area of the Central Pacific, namely in the leeward Hawaiian Is. This hard tick was described from female and nymphs taken in December 1963 on Laysan I. from 3 host species: Laysan Albatross (*Diomedea immutabilis*), Wedge-tailed Shearwater (*Puffinus pacificus*), and Ruddy Turnstone (*Arenaria interpres*) (Wilson 1964). Actually, *I. laysanensis* was discovered on Laysan I. as early as April and July 1959 by Butler (1960) from the endemic Laysan Teal (*Anas wyvilliana laysanensis*)

TABLE 3. Known hosts and localities for *Ixodes laysanensis*.

Species	Locality: French Frigate Shoals	Gardner Pinnacles	Laysan	Lisianski	Pearl and Hermes Reef	At Sea (Northern area)
Diomedea nigripes	—	—	—	—	×	—
Diomedea immutabilis	—	—	×	—	×	—
Puffinus pacificus	—	—	×	—	—	—
Phaethon rubricauda	×	—	—	—	—	—
Sula dactylatra	×	—	×	—	—	—
Sula sula	×	—	—	—	—	—
Fregata minor	—	—	—	—	×	—
Anas wyvilliana laysanensis	—	—	×	—	—	—
Arenaria interpres	—	—	×	—	—	—
Sterna fuscata	—	—	×	×	—	×
Anous stolidus	×	—	×	—	×	—
Psittirostra cantans	—	—	×	—	—	—
*Homo sapiens**	×	—	—	—	—	—
Ground Litter	—	×	—	—	—	—

*Crawling on the skin only.

(see also Butler & Usinger 1963, Wilson 1964) and was also collected on Laysan I. in March 1961 from Laysan Albatross (Woodside & Kramer 1961, unpublished Hawaiian Fish and Game Division report). Smithsonian Institution personnel recorded this species on Pearl and Hermes Reef, French Frigate Shoals, and Gardner Pinnacles in 1963 (Kohls 1966) and have since added Lisianski I. to the list of infested islands. *I. laysanensis* appears to be restricted to no one host group (TABLE 3), as the host list now includes 10 sea and shore bird species and 2 endemic land bird species. *I. laysanensis* has been collected as well from humans (crawling on the skin) and from ground litter. No specimens have yet been collected from Sand I., Johnston Atoll, despite continuous surveillance since the summer of 1963. One *I. laysanensis* larva was collected at sea from a Sooty Tern (*Sterna fuscata*) on 20 May 1965 at 16°18' N by 172°57' W. This location is approximately 320 km west of Johnston Atoll and 960 km south of the nearest *I. laysanensis* infestation (Laysan I.). Since Sooty Terns and other sea birds from the Hawaiian Is. frequently visit Johnston Atoll, it is suspected that this hard tick will eventually be carried to this atoll. No males have been recorded in nature; however, Dr Glen M. Kohls has been able to rear and obtain males from the progeny of a live female collected by me (Kohls & Clifford 1967).

A second tick species, found so far only in the northern part of the Central Pacific region, is *Ornithodoros denmarki*. The known distribution of this soft tick is from Bush Key, Dry Tortugas, Florida (type locality), associated with Sooty Terns; from Morant Cay, Jamaica, West Indies, from Brown Boobies (*Sula leucogaster*); from Solado Rock, Trinidad, West Indies, associated with nesting Sooty Terns and Brown Noddies (*Anous stolidus*); from Raza I., Gulf of Baja California, Mexico, associated with nesting gulls and terns; from Calaveras I., Gulf of Baja California, associated with gulls and cormorants; and from Manana (Rabbit) I., Oahu, Hawaii, on a Brown Noddy (*Anous stolidus*) collected 24 November 1946 (Kohls et al. 1965, Denmark & Clifford 1962). An *Ornithodoros* sp. near *denmarki* has been recorded on South I., Farallon Is., California, from nests of Western Gulls (*Larus occidentalis*) and off a European rabbit (*Oryctolagus cuniculus*) (Radovsky et al. 1967, Marshall & Nelson 1967). The range of *O. denmarki* in the Central Pacific region has now been extended to include Sand I., Johnston Atoll, where 13 specimens were collected in 1965 and 1966 from 2 Brown Noddy nests, 1 Sooty Tern nest, and 1 Wedge-tailed Shearwater nest, and it seems likely that this species will eventually be found on other islands in the northern area besides Oahu and Johnston, since the host species are known to move between the islands in the area. *O. denmarki* may already occur in such small numbers on these other islands in the Hawaiian area that it has been overlooked during collecting.

Kohls et al. (1965) state that postlarval stages of *Ornithodoros denmarki* cannot be definitely distinguished from those of *O. capensis*. Therefore, those collections containing solely postlarval stages can be identified only as *O. capensis* group. The actual distribution of the 2 species cannot be determined until numerous larvae are collected from each atoll; nevertheless, in Dr Kohls' opinion most of the material identified as *O. capensis* group is probably *O. capensis* Neumann rather than *denmarki*, since the latter species is so uncommon in the Smithsonian Institution's collection (Kohls, pers. commun., February 1965). TABLE 4 indicates those islands from which ticks identified as *O. capensis* Neumann and *O. capensis* group were collected.

Ornithodoros capensis is associated with nesting sea birds over the entire Central Pacific region. This soft tick was described from several specimens taken from nests of penguins on islands off Cape Colony, South Africa (Neumann 1901). Since 1901 *O. capensis* has been recorded around the world in the tropical and temperate regions (FIG. 2) and has been associated with 29 species of sea and shore birds throughout the world (from published and unpublished records). According to Munro (1946), it was known in the Hawaiian Is. as early as 1891, and nymphs were reported from Laysan (no collection date given) by Neumann (1901). It is presently known from 32 islands and at sea in the Central Pacific and immediate surrounding areas from 22 sea and shore bird species, as well as from man, the European rabbit, sea turtles (*Celonia mydas*), and ground litter (see TABLE 4). The hosts most frequently associated with this species in the Central Pacific region are the Sooty Tern (189 collections on 21 islands and 8 at sea) and Brown Noddy (131 collections on 15 islands). Bird movement undoubtedly has influenced the distribution of *O. capensis*, and it is suggested here that sea birds may have brought it to both areas of the Central Pacific and from other parts of the world. Further, it is suggested that the *O. capensis* population in the northern Central Pacific area does not mix with the southern Central Pacific population because of the limited sea bird movement between the 2 areas. Shore birds do move between the 2

TABLE 4. Distribution and hosts of *Ornithodoros capensis* Neumann (•) and *Ornithodoros capensis* group (+) in the Central Pacific.

Localities	Hosts: *Diomedea nigripes*	*Diomedea immutabilis*	*Puffinus pacificus*	*Puffinus nativitatis*	*Pterodroma alba*	*Bulweria bulweri*	*Nesofregetta albigularis*	*Oceanodroma markhami*	*Phaethon rubricauda*	*Sula dactylatra*	*Sula leucogaster*	*Sula sula*	*Fregata minor*	*Fregata ariel*	*Arenaria interpres*	*Sterna lunata*	*Sterna fuscata*	*Thalasseus bergii*	*Procelsterna cerulea*	*Anous stolidus*	*Anous tenuirostris*	*Gygis alba*	*Orycotalagus cuniculus*	*Homo sapiens*	*Chelonia mydas*	Ground Litter
Hawaiian Area																										
Oahu																				•						
Nihoa																			+					+		+
Necker																										+
French Frigate Shoals	+	+								+		•					•			•					+	+
Gardner Pinnacles																	+									+
Laysan	+	•	+							+	+		+				•			+	+			+		+
Lisianski										+			+		•		•			+	+			+		+
Pearl & Hermes Reef	•	•						+			+						+			+						+
Midway																	•									
Kure	•	•	•						•	•	+	+	+				•				•					
Johnston			•						•		+	+	+			•	•			•	•			+		•
At Sea (Northern area)	+																+									
Line-Phoenix Area																										
Howland									+	•	•	•		•		+	•							+		•
Baker										+										•						
Canton																+				+						+
Enderbury											+	•				+	+									
McKean			+						+	+	+		+				+			+	+			+		+
Birnie																					•					
Phoenix					+	+			+	+	+	•	+	+		+	•		•	•		•	+	+		+
Hull																				+						
Sydney																	+			+						
Christmas				+	+																+					
Jarvis											+	+														+
Malden										+				+			+			+	+					
Starbuck																	+									
Caroline																	+									
Tongareva																				+						
Marshall																										
Wake															•		+									
Taongi																	+									
Bikar																	+									
Taka																	•									
Erikub											+							+								
Eniwetok																	•			•						

areas during migration periods, but their chances of transporting *O. capensis* are small, since they spend relatively little time on islands during these periods.

The possibility of sea birds carrying ticks to other parts of the Pacific is of great zoogeographic and medical importance. Smithsonian banding data indicate that some sea birds from both areas disperse to almost all parts of the western and northern Pacific Ocean after breeding on islands in the Central Pacific region. Thus, if ticks stay attached to their hosts (as has been indicated by 10 larval collections by the present survey from sea birds at sea), there is a possibility of their being transported great distances. Although the tick dissemination potential of sea birds during postbreeding migration is high, the possibility of ticks being carried to distant islands or continents is minimal since most sea birds normally remain at sea during their nonbreeding period. Even if a tick should be carried to a distant point, however, its survival depends on the environment and the available hosts.

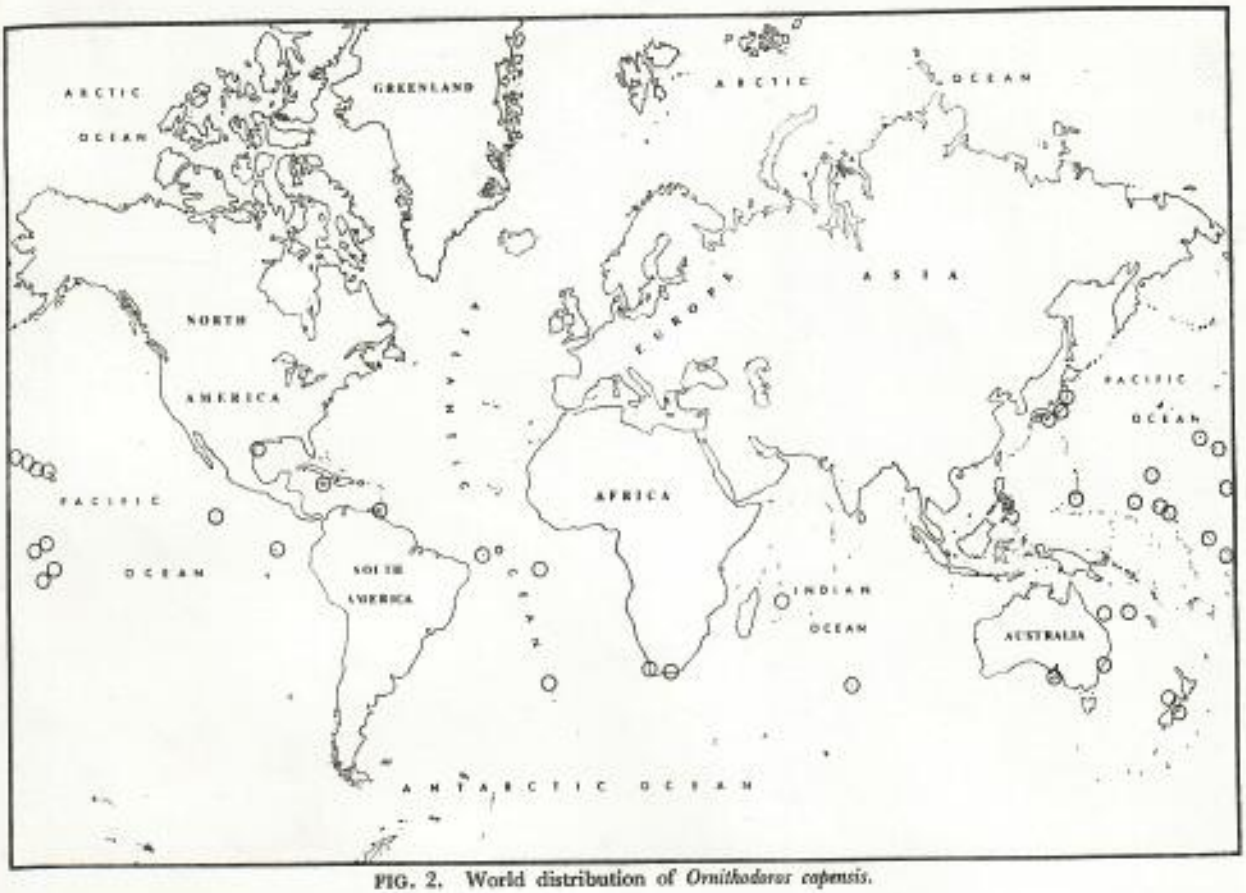

FIG. 2. World distribution of *Ornithodoros capensis*.

Many sea birds migrate annually into and through the Central Pacific region from other parts of the Pacific, although they seldom, if ever, stop on the islands of the Central Pacific. Many of these sea birds are from the Australia-New Zealand area, and the several tick species associated with them include: *Ixodes auritulus zealandicus*, *I. eudyptidis*, *I. jacksoni*, *I. kohlsi*, *I. pterodromae*, and *I. uriae* (Dumbleton 1961; Maskell 1885; Hoogstraal 1967; Arthur 1955, 1960; White 1852). The influence of migrating sea birds on the bipolar distribution of *I. uriae* has already been discussed here. Dumbleton (1961: 767) suggests that "although one of the New Zealand hosts of [*I. a.*] *zealandicus* (*Puffinus griseus*) migrates to the Northern Hemisphere the tick is not recorded there and it would appear that carriage of the tick outside the area or hemisphere in which nesting occurs, whether by regular migration or by stragglers, is seldom followed by permanent colonisation of the tick." Smithsonian Institution personnel collected a female *Ixodes pterodromae* from the ear of a northward-migrating Sooty Shearwater (*Puffinus griseus*) on 23 May 1965 in the Central Pacific at 03°10' N by 173°45' W. This tick had been attached for about 4800 km, showing the dissemination potential of the host, as well as its possible point of origin. The chances of this tick being deposited on a Central Pacific island was, as pointed out above, very low. Even if it had been deposited, however, that it would have survived is questionable, since its normal environment is a temperate rather than a tropical region.

Some of the sea bird species which breed in the Central Pacific region also breed in the Coral Sea off the northeast tip of Australia. Among them are: Wedge-tailed Shearwater, Red-tailed Tropicbird (*Phaethon rubricauda*), Blue-faced Booby (*Sula dactylatra*), Brown Booby, Red-footed Booby (*Sula sula*), Great Frigatebird (*Fregata minor*), Lesser Frigatebird (*Fregata ariel*), Sooty Tern, Crested Tern (*Thalasseus bergii*), Brown Noddy, and Black Noddy (*Anous tenuirostris*) (Hindwood et al. 1963). Near the Great Barrier Reef, the Coral Sea has a tropical environment somewhat comparable to that of the Central Pacific region. In this area *Ornithodoros capensis* again is associated with these hosts, which also harbor *Amblyomma loculosum* (Neumann 1907; Roberts 1953, 1964; Hindwood et al. 1963). The 2 *Ixodes* species occurring on nesting sea birds in the Central Pacific region have

not been found in the Coral Sea region, and *A. loculosum* is not known from the Central Pacific. Bird-banding data have shown that there is no movement between the 2 regions of sea bird species which breed in both regions. These data suggest that the Coral Sea is biologically isolated from the Central Pacific. There is evidence that sea birds from the Coral Sea may move to the Indian Ocean since *A. loculosum* occurs at Establishment I., Cargados Carajos (Neumann 1907) and at Pointe Capucin, Mahe I., Seychelles. This latter collection was taken from under the feet of a dying Sooty Tern, August 1965, by Guy Lionnet (Hoogstraal, pers. commun., April 1966).

The very low rate of interchange between sea bird populations in the Central Pacific region is very important since it virtually isolates faunistically the northern half from the southern half of that region. Tick distribution reflects these 2 populations, since movement of ticks between the 2 areas is also limited. Other arthropods parasitic on sea birds also appear to be similarly influenced. The chigger (Trombiculidae) distribution, to date, shows that 4 species occur in the northern half which do not occur in the southern half; also, 1 species of louse fly (Hippoboscidae) is presently known to occur in the southern half but has not been recorded in the northern half.

Much still remains to be learned about the distribution of sea bird ticks in the Pacific Ocean. Field personnel of the Smithsonian Institution are continuing their collection of ticks from sea birds occurring in the Central Pacific in hopes that the ticks' overall distribution and relationships to their hosts can be further elucidated. It is hoped that this paper will stimulate other workers, acarologists and entomologists as well as ornithologists, to examine sea birds and their nests for ticks, not only in the Pacific Ocean, but over the entire world.

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RELATIONSHIPS BETWEEN INSECT REPELLENCY AND CHEMICAL AND PHYSICAL PARAMETERS—A REVIEW[1]

By **Lorrin R. Garson[2] and Mary E. Winnike[2,3]**

Abstract: The pertinent literature has been reviewed from January 1940 through October 1967. The relationships between molecular constitution and insect repellency are described as well as the role of such physical parameters as boiling point and vapor pressure, molecular weight, partition coefficient, and concentration effect. The desirable properties of an ideal repellent substance are summarized, and definitions of repellency relative to this discussion are presented.

As part of our program to develop a long-lasting insect repellent and other prophylactic agents effective against pathogenic or physical impairments inflicted through the skin, we have undertaken this literature search on the relationships between chemical and physical parameters and insect repellency. Using appropriate subject headings, 5 indices (*Bibliography of Agriculture, Biological Abstracts, Biological and Agricultural Index, Chemical Abstracts*, and *Index Medicus*) were exhaustively searched from 1 January 1940 to 31 October 1967. While it was our intent to cover exhaustively the literature of all nations, one feels compelled to admit that the indices used in our survey may be, possibly, in a better position to maintain awareness of publications emanating from the North American Continent than from other parts of the world. Therefore, should we have failed to refer to some papers outside this region, we wish to assure the reader that any such omission was not intentional.

In our search, we have come across several items (Bibliography: 41, 44, 45, 56, 59, 73) directly or indirectly pertinent to the subject matter under consideration; since we experienced considerable difficulty in procuring translations, reprints, or copies of these communications or reports, we were compelled to limit ourselves to abstracts only for the purpose of this review. Because the major work in insect repellent development had been accomplished during and subsequent to World War II, we felt justified in limiting our search retroactively to 1940.

Before describing the present status of insect repellents as related to chemical and physical factors, it is necessary to enumerate the desirable qualities for these materials. Granett (1, 2), Hall and his

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