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DISTRIBUTION OF *OCHLEROTATUS TOGOI* ALONG THE PACIFIC COAST OF WASHINGTON

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ABSTRACT. Before this study, the mosquito *Ochlerotatus* (*Finlaya*) *togoi* (Theobald) had been reported from only 2 locations within the continental United States, both of which were documented in Washington State. This study used active and passive surveillance to determine the current distribution of *Oc. togoi* along the Pacific Coast of Washington. Results of the study show that small, but stable, populations of *Oc. togoi* exist in the northern San Juan Island region of Puget Sound. Geological formations in this region are conducive to rock holes and support populations of *Oc. togoi.* No members of *Oc. togoi* were found on the southwestern Washington coast, the coast of the Olympic Peninsula, or in the lower Puget Sound.

KEY WORDS *Ochlerotatus togoi,* mosquito, Washington, San Juan Islands, distribution

INTRODUCTION

Ochlerotatus togoi (Theobald) is a well-known mosquito species of coastal Asia including Russia, Japan, China, Korea, Malaysia, Thailand, and many of the northwestern Pacific islands (LaCasse and Yamaguti 1948, Tanaka et al. 1979, Sota et al. 1995). This species breeds in rock holes just above the high-tide line and may be found in freshwater or salt water. LaCasse and Yamaguti (1948) and Shestakov (1961) discussed the possibility of 2 indistinguishable forms of *Oc. togoi,* 1 that inhabits artificial containers and another that inhabits tidal rock holes. Trimble (1984) searched to no avail for *Oc. togoi* in artificial containers along the coast of British Columbia, Canada, and concluded that the rock-hole form must be the one inhabiting North America.

Belton (1980) and Trimble and Wellington (1979) provided personal information related to the 1st potential finding of *Oc. togoi* in North America, and it is still unknown whether this species was introduced via trade ships or whether it was endemic to North America. However, it was not until Sollers-Riedel (1971) reported the discovery of *Oc. togoi* in British Columbia that North American studies began on this species. As part of the North American studies, Belton (1980) reported *Oc. togoi* from Rosario Beach State Park on Fidalgo Island, Skagit County, Washington. Later, Belton and Belton (1990) reported *Oc. togoi* from Rocky (=Rock) Bay, San Juan Island, San Juan County, Washington. Since then, no documented findings of natural populations of this species have been reported in Washington or elsewhere in the USA.

After more than 10 years since the last reports of this species, we decided to search for *Oc. togoi* along the coast of Washington State to further define its distribution and abundance and to determine if it was adapting to any new habitats (e.g., artificial containers or alternate natural habitats to rock holes).

As a secondary objective, we wanted to obtain the distribution of this mosquito in support of West Nile virus (WN) surveillance efforts in Washington. In Asia, *Oc. togoi* is known as a vector of Japanese B encephalitis, as well as Brugian and Bancroftian filariasis. Japanese B encephalitis and WN are both categorized as flaviviruses, and although *Oc. togoi* is already known to be a competent vector of Japanese B encephalitis, further evaluation of this species will be required to determine its ability to vector WN. If *Oc. togoi* becomes important as a WN vector, then this study will show which areas of Washington may be affected and will provide helpful information during the development of control strategies.

MATERIALS AND METHODS

This study was conducted from April 2002 through May 2003 by using passive and active surveillance methods. Based on the reports that *Oc. togoi* may utilize artificial containers (LaCasse and Yamaguti 1948, Shestakov 1961), standard black plastic ovitraps with red velour oviposition strips were used to provide an oviposition site for gravid female *Oc. togoi.* Each trap was baited with a 1:1 mix of freshwater with local seawater. Two to 3 ovitraps were placed at 37 locations from Drayton Harbor near Blaine, WA, southward along the shores of Puget Sound, around the Olympic Peninsula, and southward to Fort Canby at the mouth of the Columbia River. The traps were placed around natural or man-made rock formations and were hidden from human view. All traps were within 50 m of the high-tide line and were checked on a monthly basis (i.e., passive surveillance).

As part of the monthly surveillance, potential mosquito habitats that were within 100 m of the high-tide line were explored for the presence of mosquito larvae (i.e., active surveillance). In May 2003, a boat was chartered (Marty Mead, North Shores Charter, Orcas Island, Washington) for a 2-

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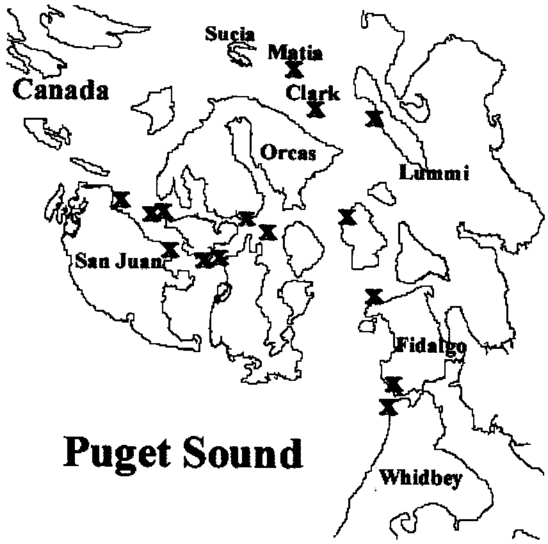

Fig. 1. Collection sites for *Ochlerotatus togoi* in Washington State.

day survey of the multiple nonmainland accessible shores of the San Juan Islands.

Personnel at the U.S. Army Center for Health Promotion and Preventive Medicine–West, Fort Lewis, WA, reared mosquito larvae collected during this study to the adult stage. These were identified and mounted as voucher specimens. For each habitat that contained mosquito larvae, a Pocket Pal™ TDS Tester (Hach Company, Loveland, CO) was used to measure the total dissolved solids (TDS) in parts per million (ppm).

RESULTS AND DISCUSSION

Results of all passive surveillance collections were negative for *Oc. togoi*; however, 1 trap near Aberdeen, WA (August 2002), collected *Culiseta incidens* Theobald. We suspect that rain may have diluted the solution in the ovitrap to the extent that it became suitable for oviposition by *Cs. incidens.* Because of the negative results, the ovitrap portion of this study was discontinued after August 2002.

When using active surveillance, *Oc. togoi* was found at 15 sites (Fig. 1 and Table 1). The sites on Whidbey Island and Lummi Island represent county records for Island and Whatcom counties, respectively. Rock holes, roadside ditches, artificial containers at 1 coastal cemetery, stored or wrecked boats, drift-log holes, coastal forest pools, and tidal marsh pools made up the bulk of the sites surveyed. In all cases, *Oc. togoi* was only found in rock holes. Very little trash was observed along the Washington beaches and hence the opportunity for mosquitoes to utilize discarded artificial containers (cans, bottles, buckets, and other containers) was limited. With landowner permission, we collected samples from artificial containers in the yards of 2 coastal homes on Lummi Island, but only *Cs. incidens* and *Culex pipiens* L. were collected from these localities.

Trimble (1984) successfully used simulated rock holes made of gray cement and smooth stone for a study in British Columbia. He also reported that he did not find *Oc. togoi* in artificial containers such as birdbaths or water pails and concluded that the rock-hole breeding strain was present in North America and had not adapted to artificial containers. Our findings support this conclusion. However, in this study, wrecked or stored boats or drift-log holes provided excellent opportunities for *Oc. togoi* to utilize non–rock-hole sites for oviposition.

Larval *Oc. togoi* were found throughout the year, but the primary breeding season in Washington appears to be from March to June, with a secondary breeding season from September to November. During the primary and secondary breeding seasons, *Oc. togoi* may be found in shaded and unshaded rock holes. Comparatively larger numbers of this species were found in deeper rock holes (>4 cm) than in shallow rock holes that remained wet throughout the breeding season. In the fall, rain filled the rock holes and triggered the beginning of the secondary breeding season. Specimens (including 3rd and 4th instars and pupae) that were collected from December through February were believed to be individuals in diapause from this secondary season. Larval diapause in North American *Oc. togoi* was reported by Galka and Brust (1987).

Rainfall in western Washington is scarce from mid-June through mid-September. During that time many rock holes become dry and thereby limit potential habitat for *Oc. togoi.* We observed that during this time *Oc. togoi* may be restricted to shaded rock holes that are deep and have the potential to be replenished by ocean spray, springs, or other small amounts of runoff.

Ochlerotatus togoi was collected from rock holes that had a TDS range between 301 and 91,250 ppm (median 6,030 ppm). The TDS in rock holes in which *Oc. togoi* was found associated with *Cs. incidens* ranged from 304 to 7,750 ppm (median 1,178 ppm). Examination of these data indicates that *Oc. togoi* can breed in habitats of extreme salinity, whereas *Cs. incidens* is limited to rock holes of low to moderate salinity. McGinnis and Brust (1983) and Trimble and Wellington (1978) discussed other aspects of the relationship of North American *Oc. togoi* to salt water.

During the primary and secondary breeding seasons when rain was plentiful, *Oc. togoi* and *Cs. incidens* were commonly seen breeding in the same rock holes; whereas during the dry season, salinity in many rock holes increased and excluded breeding by *Cs. incidens* in these sites. Rock holes that were replenished by freshwater sources were on multiple occasions observed to contain both species. Amphipods (Hossack and Costello 1979) and

Table 1. Presence and monthly occurrence of *Ochlerotatus togoi* in Washington State with information on larval habitat.

Location	Rock type[1]	Month of survey beginning in April 2002[2]													
		April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
Canoe Is.—W side	KJmm														Y
Clark Is.—SE side	Kn														Y
Cypress Is.—S. of Eagle Cliff	Jmt				Y										
Fidalgo Is.—Washington Park, Anacortes	Ju								Y	Y	Y	Y	Y	Y	Y
Fidalgo Is.—Rosario Beach State Park[3]	KJvs	N	N	N	Y	Y	Y	N	N	N	N	N	Y	Y	Y
Flower Is.—NW point	KJm														Y
Jones Is.—at boat dock	PDmt														Y
Lummi Is.—point S of Legoe Bay	Ji														Y
Matia Is.—SE side	Ec														Y
Oneil Is.—N point	pDi														Y
Orcas Is.—1.6 km E of ferry landing	KJmm														Y
San Juan Is.—point 1 km N of Friday Harbor	KJmm														Y
Shaw Is.—SW tip	KJmm														Y
Whidbey Is.—Deception Pass State Park[3]	KJmm	N	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Yellow Is.—NW side	pDi														Y

[1] *Ochlerotatus togoi* was found exclusively in rock holes. Rock types are from 1:100,000 Geologic Map of Washington—Northwest Quadrant, Geologic Map GM-50. KJmm, Cretaceous/Jurassic marine metasedimentary rocks; Kn, Cretaceous nearshore sedimentary rocks; Jmt, Jurassic metasedimentary and metavolcanic rocks undivided; Ju, Jurassic ultramafic rocks; KJvs, Cretaceous/Jurassic volcanic and sedimentary rocks, undivided; KJm, Cretaceous/Jurassic marine sedimentary rocks; PDmt, Permian/Devonian metasedimentary and metavolcanic rocks, undivided; Ji, Jurassic intrusive rocks, undivided; Ec, Eocene continental sedimentary rocks, conglomerate; pDi, pre-Devonian intrusive rocks.

[2] Y, site searched and larvae or pupae collected; N, site searched, but no larvae or pupae were found; blank, site not searched.

[3] Ovitraps, with negative results, also were set at these sites.

copepods (Albert et al. 2001) were observed in association with *Oc. togoi* during this study. Chironomids were found to be present in every rock hole containing *Oc. togoi.* Morley and Ring (1972) conducted an extensive study of intertidal Chironomidae, but did not list this association.

In addition to associated species, we observed that when larvae and pupae of *Oc. togoi* were disturbed they would routinely swim to the bottom of the rock hole and remain motionless for an extended period of time, unlike their common associate, *Cs. incidens,* which resurfaced rather quickly. Thus, disturbed rock holes that contain only *Oc. togoi* may appear to be negative for presence of the species, and if not carefully sampled, may be counted as negative by a casual observer. In rock holes with clear water and small populations of *Oc. togoi,* we ensured collection by lying next to the rock hole for close-up viewing and collected larvae from the bottom with a pipette. This characteristic behavior of *Oc. togoi* also was observed in the laboratory and provided an additional means of separating larvae of *Oc. togoi* from those of *Cs. incidens.*

While collecting in the San Juan Islands, *Oc. togoi* appeared to be more prevalent and hence significantly easier to find in certain rock formations than in others. By using geological maps acquired from the Washington Division of Geology and Earth Resources, Olympia, WA, we discovered that the rock formations found in the San Juan Islands are geologically unique, and are not found elsewhere along the Washington coast. The majority of the breeding sites of *Oc. togoi* were located in marine sedimentary rock (or variations thereof) derived from the Cretaceous, Cretaceous/Jurassic, Jurassic, the Permian/Devonian, and pre-Devonian periods (Table 1). These rocks occur at least in part on the following islands: San Juan, Spieden, Shaw, Brown, southern Orcas, the southern part and northern point of Lummi, northern Cypress, southeastern Sinclair, Vendovi, southwestern Fidalgo, northern Decatur, James, Blakely, Burrows, Allan, Center, Yellow, Oneil, and northern Whidbey. Rocks of this type also may occur on smaller islands near, or in between, these locations.

Secondary breeding strata appear to be in Cretaceous nearshore and Eocene continental sedimentary rock. These grainy rock formations give the appearance of sandstone, and are predominant on Stuart, Johns, Skipjack, Patos, Sucia, Matia, Clark, and portions of Waldron islands. Small amounts of similar rock can be found on Indian, Marrowstone, and southern Bainbridge islands, and the point across from southern Bainbridge Island. Erosion has eliminated many of the potential rock holes in these strata, but a few deep holes still exist and are utilized by *Oc. togoi.* The area south of Bellingham, WA, and along Chuckanut Mountain contains this rock and offers the highest potential for finding *Oc. togoi* on the mainland.

Other portions of the Washington coast consist of sand, gravel, large pebbles and smooth stones, or rock formations from the Quaternary Period. Rock holes generally are not associated with these formations, and little suitable habitat is available for breeding by *Oc. togoi.* Hence, we propose that the lack of suitable habitat outside of the northern Puget Sound prevents further expansion of *Oc. togoi* in Washington. In the course of our study we found multiple rock holes at Ruby Beach and Fort Canby. Although these sites offered the greatest potential for finding *Oc. togoi* in mid- to southern Washington, all active and passive surveillance results were negative.

Populations of adult *Oc. togoi* are dependent upon the number and breeding potential of each rock hole, and based upon our collections and observations, we estimate that the populations of adult *Oc. togoi* range from near zero (sites with 1 or 2 small rock holes) to perhaps as high as 1,000 (sites with several large or deep rock holes) during the primary breeding season. For the sake of comparison, the senior author had the opportunity to visit Lighthouse Park in Vancouver, British Columbia, with Peter Belton in November 2002. This locality contained a greater number of rock holes that were noticeably larger and deeper than those observed in Washington, which thereby represented a superior breeding potential for this species.

Regarding bloodfeeding, *Oc. togoi* is known to feed on humans in Asia (Tanaka et al. 1979). However, only 5 of the 15 sites that we identified were near homes or areas routinely used by humans. This suggests that humans are not the primary source of blood meals for this species. We observed several species of birds that frequented or nested near habitat of *Oc. togoi,* and mammals such as deer, raccoons, rabbits, and seals also were seen in these same areas. A variety of rodents inhabit these areas and, along with other mammals and birds, provide blood-meal opportunities for female *Oc. togoi.* Further research is needed to determine the bloodfeeding ecology of *Oc. togoi* in North America.

Currently, *Oc. togoi* is not known to transmit any diseases in North America. If it eventually proves to be a vector of WN and this relationship leads to unacceptable ecological or economic damage, then the information in this paper can be used during development of control efforts for populations of *Oc. togoi.* The logistics of finding and accessing sites for populations of *Oc. togoi* will be the most difficult aspects of their control. The suggestion is made here that larval control efforts would be more effective than adult control. State and federal officials also would have to determine a control strategy for this species, which could include either temporarily reducing the populations through the use of biological or chemical controls, or permanently reducing the populations through the destruction of rock holes conducive to oviposition by this species.

To aid the efforts of future studies, the following sites had negative results for active and passive surveillance or active surveillance alone. Sites with passive surveillance (i.e., use of ovitraps) are marked (P). Sites that had negative results for *Oc. togoi* include CLALLAM COUNTY: Sequim (P), Port Angles (P), La Push (P), Salt Creek Recreation Area, Shipwreck Point, Neah Bay; GRAYS HARBOR COUNTY: Hwy 105 at Chapin Creek (P), Hwy 105 at John's River (P), Westport jetties (P); ISLAND COUNTY: Joseph Whidbey State Park (P), South Whidbey Island State Park (P); JEFFERSON COUNTY: Ruby Beach (P), Triton Cove Tidelands (P), Port Townsend (P), Fort Worden State Park, Fort Flagler State Park, East Beach County Park, Old Fort Townsend State Park; KING COUNTY: Dash Point St. Park; KITSAP COUNTY: East Bremerton (P), Silverdale (P), Seabeck (P), Tracyton (P), Kitsap Memorial State Park, Salsbury Point County Park, Point No Point County Park, Manchester State Park; MASON COUNTY: Potlatch State Park (P), Shelton Public Fishing Access (P), Jerrel Cove State Park (P), Allyn City Park; PACIFIC COUNTY: Hwy 105 at North Cove Pioneer Cemetery (P), 4 miles east of Tokeland on Hwy 105, ½ mile south of South Bend on Hwy 101, Hwy 101 and Niawiakum River (P), boat ramp at Willapa Wildlife Refuge (P), Beards Hollow Park, Fort Canby State Park (4 areas checked, 2 ovitrap sites) (P); PIERCE COUNTY: Point Defiance Park, Solo Point (P), Steilacoom's Sunnyside Beach (P), Chambers Mill Monument on Chambers Creek Road (P); SKAGIT COUNTY: Bayview State Park (P), Bowman Road Boat Launch (P), Chuckanut Drive at Heritage Marker (on cliff) (P), SE Samish Island (P), Skagit Wildlife Area–Samish Unit (P); THURSTON COUNTY: Tolmie State Park, Nisqually Head boat ramp (P); WHATCOM COUNTY: Drayton Harbor Road (2 sites) (P), both sides of peninsula at Semiahmoo Park (P), Birch Bay State Park (P), Larrabee State Park (P), ferry landing at Lummi Island, and the northern point on Lummi Island. Sites with negative results in San Juan County from May 2003 are not listed, because of the difficulty of finding *Oc. togoi* in what we described as secondary breeding strata. Although we did not find *Oc. togoi* in our sampling of some islands with these strata, this does not preclude their existence and future surveys may find small populations on those islands.

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