Resilience and the population history of the Kuril Islands, Northwest Pacific: A study in complex human ecodynamics

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Abstract

Living in remote places can strain the adaptive capacities of human settlers. It can also protect communities from external social, political and economic forces. In this paper, we present an archaeological population history of the Kuril Islands. This string of small volcanic islands on the margins of the Northwest Pacific was occupied by maritime hunting, fishing and gathering communities from the mid-Holocene to recent centuries. We bring together (1) 380 new and previously published archaeological radiocarbon dates, (2) a new paleodemographic model based on a radiocarbon-timestamped temporal frequency distribution of archeological deposits, (3) recently published paleoclimate trends, and (4) recently published archaeological proxy evidence for changes in the extent of social networks. We demonstrate that, over the last two millennia, inhabitants of the Kuril Islands underwent dramatic demographic fluctuations. Explanations of these fluctuations are considered in the context of environmental hazards, social networks and the emergence of an East Asian “World System”, elucidating the tension between local and external adaptative strategies to social and ecological uncertainty. Results suggest that population resilience to local climate and environmental variability was achieved by virtue of social networks that maintained non-local support in times of crisis. Conversely, the expansion of the East Asian political economy to neighbors on the southern margin of the Kuril Islands appears to have undermined the adaptive benefits of regional social networks, forcing a loss of connectivity and an increase in the vulnerability of Kuril populations to environmental fluctuations.

Keyword

Kuril Islands, Archaeology, Social Networks, Resilience, Paleodemography, Climate Change

1. Introduction

As humans we live in a world connected, in which interactions link us to others and to the environment in complex socio-ecological systems. With a case study from Northeast Asia, this paper examines the interweaving of social and ecological systems and their operation at different spatial and temporal scales. We focus on an archaeological case of long-term persistence punctuated by abandonment. The case is set in the Kuril Islands, a remote chain of volcanic islands in the Northwest Pacific. We provide a model that emphasizes the role of interacting networks in explaining the rapid growth and abandonment of this chain of islands early in the second millennium AD, and the subsequent centuries-scale delay in reoccupation of these islands. The study has implications for the sustainability of human occupation in insular environments for the benefits as well as vulnerabilities of more or less connected social networks and the challenges of mitigating unpredictability in an increasingly complex and interconnected world.

2. Biogeography of the Kuril Islands

Stretching from Hokkaido to the Kamchatka peninsula, the Kuril archipelago contains approximately 32 islands varying in size from 5 km^2 to 3200 km^2 with many smaller rocky islets and outcrops (see Fig.1). Larger size and a paleogeographic connection to temperate ecosystems in Hokkaido in periods of lower sea levelshave endowed the southern islands higher biological diversity than the central and northern islands of the chain (Pietch et al., 2003). This includes a broad range of trees and shrubs (Anderson et al., 2008), terrestrial mammals (Hoekstra and Fagan, 1998), insects, mollusks and fish (Pietsch et al., 2001; 2003). The remote islands of the Kuril archipelago ("South_Central"and "North-Central" on Fig. 1) are geographically separated from the southern islands by the Bussol Strait, the largest open water strait in the island chain. According to Pietsch et al. (2003), the Bussol strait represents a significant geographic and climatic barrier to the migration of species from the southern island to the more remote islands. While smaller and ecologically less diverse, the central and northern islands currently contain high abundances of birds and marine mammal populations, including Steller sea lions (Burkanov and Laughlin 2005), harbor seals and sea otters.

Weather and climate are among the most significant challenges to life in the Kurils (Fitzhugh, 2012). The weather is strongly influenced by the maritime geography, proximity to strong ocean currents and broad North Pacific atmospheric dynamics (Rodionov et al., 2007). During winter months, the interaction between the Siberian High and Aleutian Low pressure systems forces cold air masses from the Asian continent into the Kurils producing frequent snowstorms (138 days per year on average) and stable snow cover from November until May (Ganzei et al., 2010; Leonov, 1990; Razjigaeva et al., 2008). During the summer months, weather conditions are often cool and moist with extensive fog cover (Razjigaeva et al., 2008). The interaction of the cold Oyashio current carrying water from the North Pacific and the warm Soya current carrying water from the Sea of Japan make the Kuril Islands one of foggiest places on earth, averaging nearly 215 fog-days per year on some islands (Bulgakov, 1996; Razjigaeva et al., 2011;

Tokinaga and Xie, 2009). Large and violent storms are also common during the summer months bringing heavy precipitation, strong winds and storm surges (Bulgakov, 1996).

[Insert Figure 1]

3. Cultural Occupation of the Kuril Islands

The Kuril Islands have been occupied periodically since the mid-Holocene, some islands earlier, and archaeologists have studied the culture history of the region for over 100 years (Fitzhugh et al., 2002; Kuzmin et al., 1998, 2012; Ohyi, 1975; Shubin, 1977, 1991; Stashenko and Gladyshev, 1977; Vasilevsky and Shubina, 2006; Yamada, 1999; Yamaura, 1998; Yanshina et al., 2009). Aside from the most recent Russian and Japanese settlement of the Kuril Islands, all cultural occupations were based on hunting and gathering of marine mammals, fish, birds, eggs and to a lesser degree shellfish (Fitzhugh et al. 2004). Seaweed, leafy greens, roots, and berries would have also been important despite their poor archaeological preservation (Krashenninikov, 1972). This is a typical dietshared by traditional hunter-gatherer cultures around the North Pacific Rim (W. Fitzhugh and Crowell, 1989).

3.1 Jomon and Epi-Jomon

The earliest known occupation of the Kurils is found on Iturup Island and dates to approximately 7500 cal BP. This occupation is associated with the late Initial/Early Jomon culture found in Hokkaido at the time (Yanshina and Kuzmin 2010). Available evidence indicates that continued Early and Middle Jomon occupation was limited to the southernmost islands adjacent to eastern Hokkaido. Because these islands have higher terrestrial mammal abundance and diversity compared to the islands farther north, we suspect that the earliest Jomon inhabitants maintained a more terrestrial orientation compared to later occupants who expanded into the central and northern islands after 4500 cal BP (below). Sparse archaeological materials from those early, southern occupations suggest low populations densities. The first prolonged occupation of islands northeast of the Bussol Strait occurred during the Late/Final Jomon period and persisted through the Epi-Jomon phase, an extension of the Jomon hunter-gatherer lifestyles in northern Honshu, Hokkaido and the Kurils at a time of expanding rice agriculture in the Japanese mainland. In Hokkaido and the Kurils, coastal Epi-Jomon settlements intensified marine adaptations with improved harpoon technologies (H. Okada, 1998, pp. 336). The increased pursuit of sea mammals has been connected to the movement of Epi-Jomon culture into the Kuril Islands (W. Fitzhugh and Dubreil, 1999), though we now know that central Kuril settlement started earlier, in the Late/Final Jomon phase, as the dates in this paper demonstrate. The earliest access to iron and rice dates to the Epi-Jomon period (Yamaura and Ushiro, 1999, pp. 43) and by the mid first millennium (late Epi-Jomon in transition to Satsumon), swords, armor, and other rare goods were obtained by Hokkaido groups, suggesting an expanding interaction sphere reaching as far south as the Kofun state, based in the Osaka/Kyoto region (Yamaura and Ushiro, 1999, pp. 43).

3.2 Okhotsk and Satsumon

Okhotsk people moved into the Kurils from Eastern Hokkaido about 1300 cal BP persisting for 500-600 years. The Okhotsk Culture in northern and eastern Hokkaido and the Kurils is understood as the expansion of a population or populations from the western Sea of Okhotsk who were largely distinct from that of the preceding Epi-Jomon and their Satsumon descendants (Amano, 1979; Amano and Vasilevsky, 2002; Ono and Amano, 2007; Sato, et al. 2007, 2009; Deryugan, 2008, Vasilevsky, 2005). The Okhotsk specialized in marine mammal hunting with the use of complex harpoon technologies similar to that of contemporaneous cultures of the northern Bering Sea region (Befu and Chard, 1964; Chard, 1961). Their communities were often extensive with numerous, large houses, and in some areas (but apparently not the remote Kurils), Okhotsk communities built fortified settlements and engaged in intra-cultural warfare (Samarin and Shubina, 2007; Shubina, 1999). While the Okhotsk eventually settled around the Sea of Okhotsk coast from Sakhalin to the Kurils, the Satsumon descendants of the Epi-Jomon in southern Hokkaido expanded millet cultivation and increased trade relations with northern Honshu. As a result, during the mid to late First Millennium AD, Hokkaido became divided into two spheres of influence: The Okhotsk shared cultural, ethnic and economic connections to the northwest, while the Satsumon were drawn increasingly, if indirectly, into the sphere of mainland Japan and its expanding political economy.

3.3 Tobinitai and Ainu

The Ainu emerged in the centuries after AD 1000 by a process now believed to involve assimilation of eastern Okhotsk populations into the Jomon-descendent Satsumon communities of southern and eastern Hokkaido (Hudson 1999, 2004). A transitional culture, referred to as Tobinitai, developed in this region bringing together elements of Okhotsk and Satsumon traditions (Onishi, 2003; Vasilevsky and Shubina, 2006). In Hokkaido and southern Sakhalin, Ainu communities abandoned semi-subterranean pit dwellings for rectangular, above-ground structures, gave up pottery for ironware and made more of their tools from metal rather than stone. In the Kuril Islands and southern Kamchatka, Ainu groups retained the use of pit dwellings and pottery in a form emulating iron cookware used by Ainu elsewhere (Dikov, 2004; Takase, 2013), though they did use a greater range of iron implements than their predecessors. Ainu patterns of life and culture are more clearly influenced by contact with outside traders than were any prior groups in Hokkaido or the Kurils.

The Ainu were first documented by literary Japanese starting in the 13th century and by Russians only in the early 18th (from initial contact in the Northern Kurils) (Krasheninnikov, 1972). Ethnohistoric accounts describe a hunting, fishing and gathering culture with deep spiritual connection to the natural world (Bachelor, 1901; Etter, 1949). North of Urup Island, the Ainu in the Kurils are described as having a unique subculture with distinct dialect and practices (W. Fitzhugh 1999; Krasheninnikov, 1972; Snow 1897; Tamura 1999). From the 18th century, the Kuril Ainu were increasingly impacted by the expansion of Japanese and Russian competition, settlement and control of the Kuril chain. By the time of initial contact with Russians, Kuril Ainu were living in the northern and central archipelago and had influenced the material culture of the Pacific coast of Kamchatka from the southern tip at Cape Lopatka to Nalychevo Lake, 50 km north of Avacha Bay (Dikov, 2004). Dikov (2004) attributes the material culture from Ainu sites in this region to the later Ainu period, based on interior lugged pottery ("Naiji" ware), a finding consistent with recent analysis by Takase (2013) and with the paleodemographic patterns from the Kurils reported below. Based on the continuity of lithic forms from prior Kamchatkan traditions, Dikov goes on to suggest these southern Kamchatkan sites may represent marriage of Ainu women into Old Itel’men communities rather than wholesale settlement of Ainu immigrants. From observations in the early 18th century, Krasheninnikov (1972) also suggested that the Ainu from Shumshu Island and southernmost Kamchatka Peninsula were intermarried with Itel'men (Kamchadal) natives of southern Kamchatka.

4. Paleodemography of the Kuril Islands

Archaeological survey and excavations conducted by the International Kuril Biocomplexity Project (IKIP) in 2000 and the Kuril Biocomplexity Project (KBP) between 2006 and 2010 generated a cultural radiocarbon database of 380 archaeological dates, from locations extending 1100 km from the island of Kunashir in the South to the island of Shumshu in the North. These dates were predominantly derived from wood charcoal, and the following analysis is based exclusively on a set of terrestrial carbon samples (n=364), omitting two marine mammal bone dates, three charcoal dates with post-bomb ages, and eleven charcoal dates collected from the Ainu Creek 1 site following an episode of significant anthropogenic site disturbance between field seasons. Compilation of this radiocarbon database was motivated by a desire to build statistical models of human settlement intensity in the Kurils as this varied over time and space. Such use of radiocarbon databases has become an increasingly popular source for paleodemographic estimation in archaeology over the past two decades (e.g., Rick, 1987; Shennan and Edinborough, 2007; Williams, 2012; see Brown, 2015: Table 1), though important constraints on this approach are also being actively explored (Rick, 1987; Surovell and Brantingham, 2007; Surovell et al., 2009; Williams, 2012; Brown, 2015). For example, Surovell and colleagues (2009) argue that archaeological temporal frequency distributions (*tfd*s) are likely to show a time-transgressive taphonomic bias, in which depsotis increasingly succumb to destructive geophysical processes with advancing age and are thereby increasingly underrepresented relative to younger deposits.. While efforts to quantify rates of decay have been problematic (Ballenger and Mabry, 2011; Surovell et al., 2009; Williams, 2012), it should be acknowledged that trends toward increasing temporal frequency through time are commonly observed in regional *tfd*s spanning the globe, likely owing in part to the operation of such time-transgressive taphonomic processes. However, Macinnes and colleagues (2014) have argued that the local operation of such bias in the Kurils has been minimal,so our paleodemographic modeling efforts likely capture large-scale demographic trends in the Kuril Islands with high fidelity. In particular, we focus on peak and trough structures in the *tfd* that depart from the long-term growth trend characterizing the distribution, though we do believe that some of this trend is real, as argued below.

[Insert Fig. 2]

Figure 2 presents a paleodemographic model for the Kuril Islands based on the description of temporal fluctuations in the relative frequency and magnitude of archaeological settlement occupations in the IKIP/KBP radiocarbon database. The sample *tfd* (thin line) is a summed probability distribution (*spd*), a category of *tfd* that controls for measurement imprecision in age estimation by summing up the probabilistically expressed timestamps associated with a sample of archaeological deposits (Table 1 and Supplement). To minimize the influence of investigation biase on this model, our sample includes only radiocarbon dates collected as a part of IKIP-KBP fieldwork. The creation of this database followed a sampling procedure designed to maximize geographical extent and provide comprehensive stratigraphic coverage at select locations spanning the archipelago. To minimize the over-representation of intensively dated sites through the repeated counting of identical features, while simultaneously allowing larger sites to contriute greater weight to the *tfd*, we divided each site's radiocarbon assemblage into spatially concentrated clusters (carbon specimens spaced no more than 5 horizontal meters from each other). Furthermore, within each subset thus created, we identified and pooled clusters of insignificantly different radiocarbon ages, following Ward and Wilson's (1978) method. Each site's reduced set of radiocarbon age estimates can be taken to be broadly representative of the relative temporal frequency of demographic units at the level of individual sites. Application of this pooling protocol collapsed 172 age estimates into 61 pooled estimates. Our analyses below are thus based on a sample of 253 age estimates, including 61 pooled and 192 stand-alone dates.

As discussed elsewhere (Brown, 2015, and sources cited therein), systematic error characterizes radiocarbon-supported *spd*s resulting from DeVries effects (secular variation on the concentration of atmospheric radiocarbon; Sonett et al., 1990). Efforts to control for these effects (radiocarbon calibration) typically lead to presence of many high-amplitude, short-duration structures in *spd*s (spikes and troughs) , which are exacerbated by the operation of various stochastic processes characterizing the generation of radiocarbon datasets (Brown, 2015). In our model, fine-scale variation of radiocarbon dates are smoothed by subjecting the *spd* to kernel smoothing. The distribution that results (Fig. 2, heavy black line) is expected to more closely approximate the shape of the population curve underlying the sample *tfd* (in this case, the *spd*) than does the sample *tfd* itself (Brown, 2015 and in prep; see Supplementary Information for technical details). The reconstruction of Kuril paleopopulation history presented below is based on the distribution of kernel density estimates (*KDE*) rather than the raw *spd*.

[Insert Table 1]

[Insert Fig. 3]

4.1. Kuril Population Trends

The presence of diagnostic pottery and a few radiocarbon dates from other projects (not included in Fig. 2 to ensure methodological consistency) indicate that the southernmost Kurils were occupied as early as 8000 cal BP (Yanshina et al., 2009) during the late Initial Jomon and through the Early and Middle Jomon periods (Samarin and Shubina, 2013). An earlier occupation also appears likely in the northernmost islands of Shumshu and Paramushir, close to Kamchatka, ca. 6000 cal BP (Table 1). A Kamchatkan source for this occupation may be indicated by the discovery of stone artifacts common to the Kamchatka Neolithic found on Paramushir at the Trudnaya 1 site and the Savushkina 2 site in 2006 (Fig. 3a and 3b). Unfortunately these finds were collected from surface contexts and are undated. It is reasonable that people would have made it to the northern-most and southern-most islands from the adjacent mainland coasts without moving into the more remote islands.

As argued above, Figure 2 models changes in occupation intensity in the Kurils following their colonization. Examination of this model suggests five episodes or trends in the region's population history. The first trend ("1" on Fig. 2) is one of limited growth from earliest settlement to 4500 years ago. In that time, growth concentrated predominantly in the southern islands close to Kamchatka.

The second trend ("2" on Fig. 2) is initiated with the oldest radiocarbon evidence for human presence in the remote (South Central and North Central) Kurils at approximately 3500 cal BP. The earliest archaeological diagnostics in the remote islands are attributed to Late Jomon culture, supporting the accuracy of the earliest dates. These data suggest a development of more maritime focused lifestyles and a demographic expansion across the Kurils at this time. The timing of this development is consistent with a broader shift towards coastal adaptations around the northern Sea of Okhotsk and Bering Sea (Fitzhugh, in press). Following the movement into the remote islands, our data show consistent growth from 3500 until 2000 cal BP, from the Late and Final Jomon into Epi-Jomon periods. Growth between 3000 and 2000 cal BP is approximately exponential and rapid (the mean annualized growth rate approximating 0.2% over this interval). Such a high and sustained level of growth lies at the upper limit of most hunter-gatherer populations' intrinsic capacity for growth, thus suggesting a subsidy of in-migration (Collard et al., 2010). We found Late Jomon pottery (Fig. 4) as far north as Urup Island and Epi-Jomon pottery throughout the southern and central archipelago north to the Drobnyye 1 site on Shiashkotan Island. Valery Shubin (personal communication to B. Fitzhugh) reports seeing Epi-Jomon pottery at the Savushkino 1 site in the 1970s. This observation is consistent with the appearance of Kamchatka obsidian in Epi-Jomon assemblages throughout the northern and central Kurils (Phillips, 2011) and indicates that Epi-Jomon culture bearers came in contact with Kamchatka communities or, less likely, mined their own Kamchatka obsidian well before 2000 cal BP. Epi-Jomon settlements are ubiquitous throughout the central Kurils, and in many locations their relatively small, single-room house pits are the most prevalent features across large multi-component sites as evident from both diagnostic pottery and radiocarbon dates from soil probe samples in house pits across several sites.

[Insert Fig. 4]

The third notable trend in the paleodemographic model ("3" on Fig. 2) is the decline in dated components at the end of the Epi-Jomon occupation, starting ca. 1800 cal BP and reaching its nadir by ca. 1400 cal BP. This decline began hundreds of years before Okhotsk expansion and cannot be attributed directly to Okhotsk contact, though it is possible that Okhotsk movement into northern and eastern Hokkaido had an indirect effect on Epi-Jomon populations in the Kurils. Some Kuril Epi-Jomon communities may have remained to witness the expansion of Ohkotsk culture into and through the Kurils ca.1300 cal BP, but, if so, they were a shadow of their former population. We speculate that Okhotsk colonization was made possible by in the Epi-

Jomon depopulation. There is no evidence at present to suggest conflict between the groups, despite Okhotsk use of defensive fortifications in the southern islands and on Hokkaido and Sakhalin (Samarin and Shubina, 2007). No such fortifications were identified in the central or northern Kurils. In any case, the transition from Epi-Jomon to Okhotsk appears to have involved minimal population displacement, perhaps because few Epi-Jomon communities remained in the Kurils at this time.

The fourth and fifth trends are associated with the rapid growth and subsequence, precipitous decline of population between 1300 and 500 cal BP during the Okhotsk period. In a few short centuries, the Kuril Okhotsk populations grew to rival or exceed the Epi-Jomon population peak a millennium earlier (“4” on Fig. 2). From archaeological evidence, we know that the Okhotsk settled the entire Kuril chain as far as the southern tip of Kamchatka (Dikova, 1983). As shown below, obsidian source studies indicate that most obsidian used by central and northern Okhotsk communities in the Kurils came from Kamchatka . Strangely and unlike earlier occupations, the Okhotsk population seems to have collapsed precipitously between 700 and 600 cal BP ("5" on Fig. 2).

5. Explaining Kuril Population Trends

5.1 Environmental Hazards

Environmental variability is often invoked to account for changes in the archaeological trajectories of hunter-gatherers, and we begin our exploration of the possible causes for Kuril population fluctuations with a discussion of the environmental factors that might have negatively (or positively) affected Kuril settlement. The most evident environmental factors include natural hazards such as volcanic eruptions and tsunamis as well as changes in the climate and marine ecosystem that would have affected mobility and subsistence (Fitzhugh 2012).

Located on the active Kuril-Kamchatka subduction zone, the Kuril Islands have experienced at least thirty-three volcanic eruptions in the last 300 years with twenty erupting in the last seventy years alone (Nakagawa et al., 2008; Ishizuka, 2001). Nakagawa and colleagues (2008) report approximately eighty volcanic eruptions across the island chain in the last three millennia, including two caldera eruptions (Medvezhya on Iturup in the southern islands and Ushishir in the central islands) and four large Plinian eruptions (Zavaritsky once and Sarychev twice in the central and Severgina, three times in the northern islands) (see Fig. 2). In addition, Nakagawa and colleagues (2008) identify periods of greater and lesser Kuril volcanic activity throughout the Holocene, with some of the most intense eruptive intervals falling during the Epi-Jomon population explosion.

Despite the occurrence of hazard events during periods of high population density in the Kuril Islands, there is little evidence to suggest these events precipitated population decline. As highlighted in Fig. 2, major eruptions in the Kuril archipelago occur at various phases of population growth and stasis. The caldera-forming Medvezhya (ca. 2400 cal BP) and Ushishir (ca. 2200 cal BP) eruptions occurred during times of population growth that continued in the immediate post-eruption years. Most eruptions—even some of these large ones—would have had only local impacts, leaving the majority of the Kuril population unaffected and often giving adjacent communities the chance to move away temporarily. Every once in a while an eruption could have had more extensive impacts, and it may not be coincidence that both population declines start soon after major eruptions. On the other hand, the fact that people returned to the Rasshua 1 site to settle on top of thick Ushishir tephra soon after that caldera eruption, suggests a relatively benign impact (Fitzhugh 2012).

The tectonic environment of the Kuril archipelago also generates numerous earthquakes and related tsunami events. Geological data collected over the last sixty years demonstrates the occurrence of at least thirty-four earthquake and related tsunami events within the Kuril archipelago (NGDC, 2013). Analysis of paleo-tsunami deposits indicates that similar events likely occurred in this region throughout the Middle and Late Holocene (MacInnes et al. 2009). Colleagues continue to work on the quantification of earthquake and tsunami frequency and intensity from field studies. Preliminary indications are that major tsunami events recur at any given location (but especially on the Pacific side and near passes) every 100-200 years. The archipelago itself might see a major tsunami somewhere every several decades and if people were in contact with each other, as we expect they were, it is likely that they were aware of the risk and took efforts to protect themselves and their critical infrastructures (boats and houses). As noted elsewhere, the placement of settlements on elevated terraces suggests awareness and effort to avoid direct tsunami impacts (Fitzhugh, 2012). Damage to marine ecosystems from tsunamis may have been fairly temporary and most often on the Pacific sides of the islands. Thus, opportunities would normally exist to move to the Okhotsk Sea side to find unaffected resource zones.

5.2 Climate Change

Fluctuations in climatic could have had direct or indirect effects on the dynamic population history of the Kuril Islands. Boat travel, a necessity for foraging and connecting with neighbors, could become increasingly risky in stormier periods. A range of climate variables could change the ecological character and productivity of nearshore marine ecosystems. Research is still needed to meaningfully characterize the mechanisms linking climate trends and their implications for travel and subsistence during the mid to late Holocene. Here we report the more general climate patterns revealed by paleoclimate research conducted under the umbrella of the Kuril Biocomplexity Project.

Paleoclimatological proxy data from a number of sources on or near the Kurils point to major fluctuations in temperature and aridity through the Holocene. Pollen analysis from peat excavations and lake cores in the Kurils show major changes from the early to late Holocene with sea level highstand marking the Holocene Optimum between 7500 and 6600 cal BP (Lozhkin et al., 2010; Razjigaeva et al., 2013). The late Holocene was generally cooler and stormier than the early Holocene, with a more active and variable Aleutian Low pressure system dominating winter weather in the North Pacific. This pattern resulted in more intense cold and dry winds off the Siberian mainland, a frozen Sea of Okhotsk in winter, and generally more stormy conditions overall. At the same time warm tropical waters could be pushed north along the Pacific coast of Japan—sometimes reaching the southern Kurils— creating more mild conditions in that region (Razjigaeva et al., 2013, pp. 135).

Expansion of human settlements into the central Kurils follows mid to late Holocene "Neoglacial" cooling trend, while the most extreme cold intervals coincide with declines in population (Fig. 2). Razjigaeva and colleagues (2013) report the following mid to late Holocene trends:

- After the Holocene Optimum, a brief cooling is evident from 5400-5000 cal BP (4700-4500 ^{14}C BP). This cooling was most prominent in the central Kurils, while temperatures remained relatively warm in the South Kurils.
- From 5100-3400 cal BP (4500-3200 ^{14}C BP), the Kurils were warmed again, especially in the southern islands, and precipitation increased. Jomon expansion in the central islands occurred towards the end of this phase, though population numbers appear low.
- From 3400 to 2400 cal BP (3200-2400 ^{14}C BP), the Kurils cooled by as much as 2-3 degrees C and precipitation resulted in heavy, winter snow cover. Stronger then previous southerly spring and summer winds are indicated by the presence of windblown pollen from 2750 years ago to present.
- The cooling trend intensifies to its maximum during the interval from 1650-1200 cal BP (1760-1270 ^{14}C bp) when conditions were not only cold but also drier than previously, suggesting a southerly extent of the cold Oyashio current and dry, cold winds off the frozen Sea of Okhotsk in winter. Whether or not there is a connection, this interval corresponds with the decline of Epi-Jomon settlement in the Kurils.
- From 1200-670 cal BP (1270-700 ^{14}C BP), a warm trend prevailed, especially on the continent, while the Kurils experienced mild warming to just slightly above late 20th century/early 21st century ("modern") averages. This interval corresponds with the Okhotsk expansion into and through the Kurils and—for what it is worth— terminates at roughly the same time as the collapse of Kuril Okhotsk settlement.
- Cold winters, cool summers and high precipitation dominated the interval from 670 to 100 years ago or so. Temperatures declined 1-2 degrees C and the cold Oyashio once again appears to have pushed south, but this time high precipitation indicates prevailing winds coming from open water. Mild regression of the sea level once again exposed unconsolidated sand and dunes were built in the southern Kurils. The Kurils appear to have been abandoned as the weather turned cold. They were reoccupied—by Ainu communities—before the climate had yet rebounded, though populations were never as large as they had been.

As described, it is easy to see a relationship of some kind between climate trends in the late Holocene and Kuril population trends. While the remote islands were only significantly occupied after the end of the Holocene Climatic Optimum, possibly hinting at poor conditions associated with extreme warming, human populations appear to have done their best in cooler but still moderately warm climates within the colder late Holocene/Neoglacial phase, and may have declined or completely abandoned the remote islands in the coldest periods (Fig. 2). These relationships could be clarified with higher resolution climate data and better understanding of the mechanistic links between climate and maritime hunter-gatherer welfare in the region.

Recent research in North Pacific oceanography suggests that colder temperatures around the N. Pacific Rim (esp. Gulf of Alaska and eastern Aleutians) may lead to enhanced marine productivity through production of fattier planktons and more robust forage fish stocks (Trites et al., 2007). Other data suggests that some taxa (such as cod, pollock, and anchovies) do better—in some areas at least—with warmer waters and stronger Aleutian Low pressure conditions (Chavez et al., 2003). Overall, it is likely that environmental factors played an important role in the settlement, habitation and abandonment of the Kuril Islands but these factors require more study. We believe the environmental variables are important but incomplete aspects of the human settlement story. Hunter-gatherers are known to have a number of strategies available to mitigate environmental variability and uncertainty (Fitzhugh et al., 2011; Halstead and O'Shea, 1989; Wiessner, 1977). We think the story is more complicated, specifically because it also involves social dynamics in play at various spatial scales.

5.2 A Network Approach

To make better sense of the Kuril settlement history, we propose the following framework to explore the Kuril population trends identified above. Specifically, we suggest that the formation of and reliance on social networks played a key role in both stabilizing populations through moderate environmental turbulence at one spatio-temporal scale while increasing vulnerability to environmental and socio-economic fluctuations at larger spatial scales. Drawing from the information-networks model (Fitzhugh et al., 2011), we propose that during periods of expansion and colonization of novel landscapes, extensive social networks are likely to be in demand as they provide access to regional information and resources that are crucial when uncertainty about the new environment is at its highest. In the Kuril Islands, this would likely be when populations initially expand into the more remote central islands during the early portion of the Epi-Jomon and the early half of the Kuril Okhotsk occupation (which coincides with the Middle Okhotsk in Hokkaido). However, after the period of initial colonization and 'settling in,' environmental uncertainty should decrease through individual learning and collective experience within the new environment (accumulation of local and traditional knowledge). At this point, social networks should either be maintained or reduced. Despite the high costs of extensive social networks, they should be maintained for communities living in sparse and highly unpredictable and hazardous environments (Fitzhugh et al., 2011). Network contraction is expected under most other conditions, where network costs are reduced by trimming the most expensive connections in proportion to greater understanding of and local adaptation to environmental variability. We expect that partners living farthest away are most likely to drop out of such contracting networks.

Our initial prediction is that the networks of the Jomon/Epi-Jomon and Okhotsk would have become smaller and more isolated over time as growing experience with the landscape lowered the perceived value of social contacts from beyond the local area. This would be true *unless* the Kurils were chronically vulnerable so that networks remained essential for dealing with occasional local insufficiencies. In this case, the increased security of the extensive social network could be counter-balanced by unintended consequences of being dependent on that larger network. These unintended implications include susceptibility to external forces or hazards, such as diseases (McGovern et al., 1988), changes in the economic and political dynamics affecting other parts of the network, and the potential loss of self-sufficiency due to an increased reliance on non-local materials. In fact, in some cases trade and information once integral to expansion or population growth could later become significant hazards in their own right. In essence, island-living could put remote communities into a precarious balance between managing local environmental hazards and non-local social hazards.

5.3 A Tale of Two Networks

Based on archaeological and historical evidence, we argue that the Epi-Jomon and Okhotsk occupations of the remote Kuril Islands developed two somewhat different social network strategies that contributed to their different population histories. Throughout the Epi-Jomon—well after ancestral Jomon settlements were established in the islands—networks appear to have had limited extent. These networks nevertheless served to prevent Epi-Jomon communities from short-term impacts. For the Okhotsk, by contrast, regional networks were more extensive, well after colonization—potentially for economic benefits—in ways that may have led to an over-dependence on non-local assistance in times of local crisis. While neither strategy prevented decline, the rate of population loss was significantly different in each case, with the Epi-Jomon experiencing a gradual population decline over 300-400 years while the Okhotsk disappeared completely in less than 100 years.

As detailed elsewhere (Phillips and Speakman, 2009; Phillips, 2011; Gjesfjeld and Phillips, 2013; Gjesfjeld, 2015) evidence for changes in Epi-Jomon and Okhotsk network structures are based on a series of geochemical sourcing studies using both obsidian and pottery. The use of multiple material types is advantageous in this research as they highlight exchange patterns of differing intensities at different spatial scales. Because obsidian is not found locally in the island chain but can be acquired nearby in Hokkaido or Kamchatka, the sourcing of obsidian throughout the islands is informative of exchange and connections to regions beyond. In contrast, raw clay deposits needed for making pottery are found throughout the central islands with geochemical differences that discriminate clay sources from different regions of the archipelago (Gjesfjeld, 2014). As a result, pottery sourcing studies are more indicative of connections over local or regional scales. These sources, when taken in tandem, allow us to draw conclusions about the scale and intensity of social networking within and beyond the island chain.

Our interpretation of Epi-Jomon network contraction in the central islands is based on this combination of pottery and obsidian evidence. The geochemical sourcing of pottery from the central islands suggests a highly localized network structure. At the site of Rasshua 1, located on the central island of Rasshua, 25 sherds classified as Epi-Jomon (based on presence of cord-marking and consistent with radiocarbon dates) were analyzed for trace elements. A high proportion of sherds (88.5%) had significantly similar geochemical signatures. Using the criterion of abundance postulate (Bishop et al., 1982), we interpret these results to indicate that most ceramic artifacts were locally produced. The remaining sherds (11.5%) are considered non-local or imported to the site. It is intriguing to note that two thirds of the non-local sherds from Rasshua 1 originate from the lowest levels of the site (Level 7C and 8) suggesting an importation of pottery to the site during its initial settlement.

Lithic analysis of obsidian recovered from Epi-Jomon contexts in the central islands (including Rasshua) also indicates a very low usage of (non-local) obsidian (0.6% of total by mass) compared to the overall lithic assemblage, which is dominated by local basalts (59.3%) and cherts (28.5%). Based on results from the geochemical sourcing analysis of obsidian artifacts, during the Epi-Jomon period central island inhabitants equally procured obsidian from both Hokkaido (52%) and Kamchatka (48%) sources. However, based on the resolution of the data we are unable to conclude whether procurement networks to both Hokkaido and Kamchatka were in use at the same time or whether Epi-Jomon inhabitants changed their procurement networks while occupying the central region. The fact that northern island obsidian is predominantly from Kamchatka and southern island obsidian from Hokkaido, does seem to imply that the overlap in the central islands was connected and concurrent with the larger pattern.

Compared to the low level of Epi-Jomon interaction, exchange during the Okhotsk occupation tends to be less localized. Results of pottery sourcing at the site of Vodopodnaya 2, on the island of Simushir, suggest that more Okhotsk pottery was non-locally produced than that of Rasshua 1's Epi-Jomon deposit. Based on geochemical analysis of 25 sherds (all identified as Okhotsk), only 24% of sherds demonstrated similar geochemical signatures that could be interpreted as locally produced pottery, with 76% of pottery potentially manufactured non-locally. Overall elemental variability in clay is higher at the site of Vodopodnaya than Rasshua, but not high enough to account for the difference in pottery assigned to a local group, suggesting these differences are indicative of more imported pottery (Gjesfjeld 2014).

Obsidian in the central islands is also found in higher relative abundance during the Okhotsk period, with a small but higher proportion (1.9%) of the total lithic assemblage. However, even though Okhotsk culture originates in northern Hokkaido and southern Sakhalin, almost all obsidian raw material in the central islands originates from Kamchatka during this period. While this finding does not rule out exchange relationships with Hokkaido populations—and our sample of Okhotsk materials from the southern islands appears to be artificially low—it does suggest exchange relationships with Kamchatka may be more important on average in this period. In sum, Okhotsk populations appear to have been dependent on non-local contacts in terms of their overall use of pottery and non-local raw material. The northerly focused obsidian trade may be indicative of a loss of social network support to the south – a development that may have ultimately led to the collapse of the occupation.

6. Social Dependency in Relative Isolation (Discussion)

Our research indicates that people colonized all of the Kuril Islands no later than 3500 years ago, expanding in population more or less continuously for the next 1500 to

2000 years during the Late/Final Jomon and Epi-Jomon periods. During this expansion, long-distance social networks were established and maintained with both Hokkaido and Kamchatka neighbors, as indicated by obsidian raw materials sourced to both regions. Nevertheless, these communities maintained largely self-sufficient lifestyles and the predominant scale of interaction/mobility was with neighboring islands, indicated by the more local scale for pottery source catchments and the social interactions that would flow across them. Interestingly, the dominant source areas of obsidianappear to have been the ones in closest proximity (Kamchatka or Hokkaido). We see this as a reflection of the high cost of travel and tendency to look for the closest sources of raw materials.

These data suggest a healthy balance of local adaptation and the ability to deal with seasonal to inter-annual, localized resource variability. This is expected for self-sufficient population with established local and traditional knowledge about their place, who nevertheless rely on larger social networks for occasional trade and maintenance of social contacts that could be tapped for assistance in rare times of need. Living above the reach of most tsunamis, moving periodically to avoid local resource failures or volcanic eruptions, and developing traditional knowledge about how to find food in difficult times may have limited the necessity of more regularized, long-distance interactions. The combination worked for millennia.

The decline of Epi-Jomon settlements was gradual, transpiring over several hundred years from ca. 2000 to about 1500 cal BP. This decline cannot be attributed to conflict with Okhotsk people who showed up in Eastern Hokkaido and then the Kurils, centuries after the onset of Epi-Jomon declines. The gradual pace of population loss also implies that the cause was not a catastrophic event such as a major tsunami or short term ecosystem crash of the sort that could be mitigated through the temporary reliance on distant exchange partners. We conclude that low level, long-distance social networking inferred from the obsidian distributions was effective. The decline of the Epi-Jomon may instead relate to deterioration of living conditions in the Kurils of the sort that could emerge from a sustained change in ecological productivity due to climate change, or alternatively, people may have been lured away by the development of new opportunities elsewhere. In either case, possible causal mechanism/s for this decline are not easily identified beyond the simple correlation of population decline and the onset of cold conditions in the late Epi-Jomon.

The expansion of the Okhotsk cultural group into the Kurils appears rapid in Figure 2, but was not necessarily any faster than that of the last 500 years of Final Jomon/Epi-Jomon expansion (from 2500-2000 cal BP). In both cases, the rate of population growth (estimated around 0.002 persons per year) is within the range of ethnographically known, hunter-gatherer growth rates and could have been sustained intrinsically with only minimal immigration (Brown, in prep). By contrast, the rate of loss at the end of the Okhotsk settlement was extremely rapid and indicates near or total abandonment of the islands between 700 and 600 cal BP.

To make our argument for the Okhotsk collapse, we need to introduce the concept of the expanding "East Asian World System," of which the Okhotsk cultural phenomenon sat on the margins (Hudson, 2004). First, we think it likely that the galvanization of the Okhotsk 'culture' in the western Sea of Okhotsk region was stimulated—at least indirectly—by political-economic developments in adjacent regions of mainland East Asia. In particular, emerging polities of Manchuria (Heishui or Black Water Mohe) and Bohai (Parhae) kingdoms sought to profit as intermediaries in commodities markets linking wild products from the Sea of Okhotsk and elite markets of more densely settled (and commodities hungry) Korea and China. Demand for trade in exotic commodities was growing and hunter-gatherers of the Sea of Okhotsk were in a position to supply products in return for access to exotic goods including ironware, rice, cloth, alcohol, and weapons (Amano et al. 2013; Smale 2014; Yamaura 1998). However, at least in Hokkaido, the Okhotsk appeared to be only marginally engaged in this trade for distant goods, while their contemporaries, the late Epi-Jomon and descendent Satsumon cultures were increasingly influenced by goods and practices imported from Japanese society to the south (Hudson, 2004).

We propose that Okhotsk formation and expansion into Hokkaido may have been fueled by this growing market and either a desire—among disinherited Okhotsk families—for uncontrolled territory to procure trade items, or to escape the heavy hand of domineering chiefs, whose control of hunting grounds and trade routes and whose pursuit of power made life hard for subordinates. This scenario helps explain why relatively few durable trade goods from political centers of Japan and East Asia are found in Okhotsk sites in Hokkaido and the Kurils. Okhotsk communities may have also had some access to commodities trade out of centralized Japan, explaining the use of Honshu iron in Late Okhotsk smelting (Amano et al. 2013). But the Satsumon people—direct descendants of the Epi-Jomon in Hokkaido and occupying southern and central Hokkaido as well as northern Honshu—had much greater access to these markets, potentially insulating or excluding the Okhotsk. Okhotsk groups who migrated east and settled the regions around Shiretoko and Nemuro Peninsulas and who—presumably—networked with the expanding populations that soon after filled the Kurils may have been looking for new sources of exploitable trade items or just a place to escape demand for commodity production.

Based on our evidence, once in the Kurils the Okhotsk pursued more social interaction over distance than their Jomon/Epi-Jomon predecessors. Our data are incomplete on this count because our samples don't include Okhotsk materials from the southern islands, but we believe that Okhotsk settlement in the Kurils likely retained strong connections with kindred communities in Eastern Hokkaido for several centuries. Okhotsk settlements are known from the southern islands based on surface collections of diagnostic pottery and limited excavations. In any case between about 1000 and 700 years ago, something disrupted these connections, whatever they were, something that rendered the occupants of the remote and northern Kurils especially vulnerable.

Two alternative scenarios present themselves. First, the remote islanders could have been abandoned in their trade networks by neighbors in the southern Kurils and Hokkaido. Between 1000 and 700 years ago, Okhotsk occupants in these more southerly regions became increasingly incorporated into interior-focused Satsumon traditions (Tobinitai phase: Hudson 1999; Onishi 2003). Since Satsumon communities were much more engaged in commodities trading with mainland Japan, their expansion into Eastern Hokkaido and incorporation of Okhotsk communities would have been accompanied by enhanced opportunities to participate in that trade. Since Japanese markets of the day were particularly focused on interior forest and stream products, and not marine products, the absorption of southern Okhotsk communities could have decreased the need or interest for those communities to engage in reciprocal social and trade networks with remote islanders. People living in the remote and environmentally tenuous central and northern Kurils found themselves cut-off from trade networks to the south on newly formed social networks to Kamchatkan neighbors (presumably the ancestors of the Itel'men/Kamchadals). This reduction in access to social networks would have rendered Kuril communities especially vulnerable just as colder climate triggered changes in the frequency and intensity of ecological crises.

A second scenario—equally plausible, not mutually exclusive, and harder to evaluate—relates to the increased probability of exposure to communicable diseases when engaged in more extensive social networks. Small pox entered central Japan with Buddhism in the 735 C.E. and ravaged the country—by one estimate killing up to 1/3 of the Japanese population (Suzuki 2011). Over time the disease became less virulent in the urbanized populations of Japan, but would have remained especially lethal to small populations in remote locations, once contracted. Thus, it may not be a coincidence that the Kuril Okhotsk population collapsed catastrophically, just as their neighbors to the south were becoming more engaged in trade and social networks oriented to Japan. It may also be that Kuril Okhotsk chose to cut ties to the south to avoid exposure to epidemic diseases that may have developed there.

We do not know for certain how Okhotsk and Kamchatkan communities got along, but the loss of networks to the south may have increased the pressure to engage with Kamchatkan groups when natural hazards or ecological downturns affected life in the remote Kurils. It is also possible that Kamchatka served as a refuge to those forced to leave the remote islands, though no Okhotsk settlements have been found along the coasts of Kamchatka. We suspect that the decline in social connections to the south and tenuous connections to the north made persisting in the Kurils particularly precarious for Okhotsk occupants after 700 years ago when Little Ice Age cooling increased the probability of severe bad years.

We propose that the Kuril Okhotsk were made increasingly isolated in the 13th century C.E. in way that made them more vulnerable to environmental hazards that they could no longer mitigate successfully with help from social networks. This could have occurred because southern neighbors lost an economic incentive to support their northern neighbors or because epidemic diseases wiped out southern trading communities or Kuril Okhotsk communities themselves. Cut off from southern contacts and lacking the bonds of common culture or kinship with Kamchatkan populations, social safety networks along with their complementary ecological benefits deteriorated, leaving the Kuril Okhotsk more vulnerable to natural hazards and bad resource or storm years. In this scenario, rapid cooling (experienced as an increase in the frequency of particularly cold years) would have been disproportionately hard on Kuril Okhotsk communities and a combination of catastrophic mortality, poor subsistence returns and hunger, increased inter-group conflict (though evidence for warfare is absent in most of the Kurils), and emigration could have led to the rapid depopulation our paleodemography data reveal.

7. Conclusion.

In this paper we have explored an empirical model of Kuril Island demographic history based on archaeological radiocarbon frequencies. The data support mid Holocene expansion into the remote central islands, followed by two periods of sustained growth punctuated by significant population declines. Adaptation to the remote islands would have required a combination of adept maritime technologies and skills as well as social networks at various scales. Those networks were needed for materials not locally available, information about natural and social resources and hazards, and friends to call on when conditions failed at home. We presented data that reveal different patterns of social networking in Epi-Jomon and Okhotsk periods, along with environmental data on the effects of climate on local temperatures and precipitation.

While the data presented suggest that human populations responded in some degree to climate change, at least in the last 2000 years, we have argued that the human response to climate change was indirect at best. We argue that understanding the population variability in the Kurils demands an approach that considers the intersection of social and natural variables that together affect the vulnerability of small human populations. We argue that the Jomon/Epi-Jomon emphasis on local adaptation and weak connections to the outside provided a remarkably successful strategy. They persisted in the archipelago for 3000 or more years. Their decline was gradual, probably related to a general decrease in the overall productivity of the Kuril ecosystem. We believe that the Okhotsk—one way or another—were victims of the expanding East Asian World System that—while they did not directly depend on it—undermined the robustness of their more regional trade network.

We believe that there are lessons in this history for contemporary society. The hyper-connected world we live in today comes with its own advantages and vulnerabilities. Being connected gives us nearly instant access to information. Like the ancient settlers of the Kurils, this information helps us to navigate our world and avoid some pitfalls (or to deal with them, when we have to). By the same token, we are so deeply dependent on our complex and interconnected network, that any loss of connectivity can create chaos and panic. The people who are most vulnerable are those with unequal or unreciprocated dependence on their network partners. The Jomon/Epi-Jomon appear to have interacted with more or less co-equal partners at low levels of intensity. Their exchange was based on reciprocation and minimal interdependence. The Okhotsk, by contrast were influenced by a growing economic ‘world system’ that encouraged asymmetric relationships and created unprecedented vulnerability to the whims of environment as well as markets, social developments, and epidemics beyond their control or even awareness. Chances for sustainability are improved—but not ensured over long enough time periods—with a healthy balance of self-sufficiency and a modest social network, with limited interdependence.

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Supplementary data:

S.1.: Pooled radiocarbon dates used in the paleodemography model to avoid over counting of statistically indistinguishable and context redundant dates.

S.2. Summed probability distribution and kernel density estimate calculation, with Supplementary Table 1 listing dates pooled in the production of the spd (Fig. 2).

Supplementary data for:
Paper: Resilience and the population history of the Kuril Islands, Northwest Pacific: A study in complex human ecodynamics
Authors: Ben Fitzhugh1*, Erik Gjesfjeld2, William Brown1, Mark J. Hudson3
Corresponding author: E-mail: fitzhugh@uw.edu

Summed probability distribution and kernel density estimate calculation

The summed probability distribution (*spd*) presented in this paper is calculated as

$$u(t) = \frac{1}{n}\sum_{i=1}^{n} f_i\big(t|r_i, s_i, \mu_\rho(t), \sigma_\rho(t), \theta\big) \quad (1),$$

where $u(t)$ is the summed probability density of the sample at time t (cal BP; hereafter, 'summed probability function'); n is the sample size; and $f_i\big(t|r_i, s_i, \mu_\rho(t), \sigma_\rho(t), \theta\big)$ is the posterior probability density of the ith data point in the sample at time t, conditional on the data point's conventional radiocarbon age and measurement error (r_i and s_i), the calibration curve model's expected radiocarbon age at time t and its associated standard deviation ($\mu_\rho(t)$ and $\sigma_\rho(t)$), and the parameter(s) defining the prior probability distribution (abbreviated θ). In this case, a uniform prior distribution was used, truncated below at 0 cal BP, such that the posterior calendric age estimate is proportional to the likelihood function.

In theory, the kernel density estimator applied in this paper is calculated as

$$\hat{f}(t) = \int_{0}^{50000} u(\tau)\, K(t-\tau|h)\, d\tau \quad (2),$$

where $K(t-\tau|h)$ is a kernel function at time τ, centered on t and conditional on a bandwidth h. When applied to *spd*s in this way, the density estimator described in Eq. 2 is tantamount to a moving distance-weighted average on the *spd*, smoothing away the dramatic peaks and troughs that characterize *spd*s. However, because the *spd* is discretized at five-year intervals, $t \in \{0,5,\ldots,50000\}$, the kernel density estimator applied in this paper only approximates Eq. 2,

$$\hat{f}(t) \cong \frac{\sum_{\tau\in\{0,5,\ldots,50000\}} u(\tau) \times K(t-\tau|h)}{5 \times \sum_{t\in\{0,5,\ldots,50000\}} \sum_{\tau\in\{0,5,\ldots,50000\}} u(\tau) \times K(t-\tau|h)} \quad (3).$$

The shape of the kernel function applied in this case is a Laplace or double-exponential kernel,

$$K(t-\tau|h) = \frac{0.5}{h} \times e^{\frac{|t-\tau|}{h}} \quad (4).$$

The general form of the experimental bandwidth selection rule employed in this paper is

$$h = \theta_1 \times IQR^{\theta_2} \times n^{\theta_3} \quad (5).$$

where IQR is the interquartile range of the *spd* and θ_j is the jth parameter, which acts either on the sample dispersion (θ_2), sample size (θ_3), or the product of these two transformed sample attributes (θ_1). The first parameter is constrained to positive real numbers, while the latter two may take on any real value. Assuming that the second parameter is positive and the third is negative, the bandwidth adapts to the sample by increasing either in the case that sample dispersion increases or sample size decreases, in other words in any case where the temporal density of observations in the sample decreases. Values employed for the parameters in this study are

$$\theta = \left\{-\frac{1}{\ln(0.05)}, 1, \frac{1}{6}\right\} \quad (6).$$

While this parameterization greatly diminishes the appearance of extreme structures in the Kuril kernel density estimator distribution (*KDE*) vis-à-vis the *spd* upon which it is based, these parameters are somewhat arbitrarily selected. Simulation research is being undertaken to optimize the adaptiveness of these parameters (Brown, in prep).

Supplementary Table 1: Pooled radiocarbon dates for the production of the Kuril spd paleodemography model.

Island	Site Name	Pooled Catalog nos.	Pooled Lab nos.	^{14}C age	95.4% Credible Interval (cal BP)[2]
Kunashir	Rikorda 1	KBP 0115, 0107	OS-58967, 58975	2234±19	2329-2157
Iturup	Berezovka 1	KBP 0084, 0082, 0080, 0081	OS-93593, 93592, 93590, 93591	2076±15	2113-1995
Urup	Ainu Creek 1	KBP 0538, 0510, 0323	OS-59345, 59344, 59348	2570±15	2749-2720
Urup	Ainu Creek 1	KBP 0531, 0534, 0507	OS-95615, 98017, 59376	2457±17	2702-2379

Urup	Ainu Creek 1	KBP 0444, 0443	OS-59375, 59795	2044±32	2114-1925
Urup	Ainu Creek 1	KBP 0447, 0290	OS-59343, 59347	1302±19	1288-1183
Urup	Ainu Creek 1	KBP 0272, 0268	OS-59382, 59205	1140±18	1173-975
Urup	Kama	IKIP 0315, 0313	AA-40949, 44269	966±27	933-796
Urup	Kama	IKIP 0326, 0327	AA-40950, 41560	2142±28	2302-2009
Urup	Kama	IKIP 0331, 0329	AA-44272, 41561	2010±30	2041-1885
Urup	Kama	IKIP 0311, 0314	AA-44267, 41557	1355±27	1317-1187
Urup	Kapsul	KBP 0256, 0255	OS-59385, 59497	99±20	260-26
Urup	Kompaneyski 1	KBP 4308, 4310	OS-98006, 98007	2003±17	1994-1900
Urup	Tokotan 4	KBP 0418, 0419	OS-95613, 95614	1300±20	1287-1183
Chirpoi	Peschanaya Bay 1	IKIP 0292, 0293	AA-42209, 42210	2135±30	2300-2004
Chirpoi	Peschanaya Bay 1	IKIP -288, 0284	AA-40947, 42206	2002±34	2041-1876
Chirpoi	Peschanaya Bay 1	IKIP -282, 0295, 0289	AA-42204, 42211, 42207	1892±24	1893-1739
Simushir	Brotona Bay 2	IKIP 0152, 0155	AA-44263, 44265	914±28	919-763
Simushir	Brotona Bay 2	IKIP 0154, 0153	AA-44264, 40944	1710±28	1698-1554
Simushir	Brotona Bay 2	IKIP 0149, 0148	AA-44260, 44259	1139±29	1174-968
Simushir	Brotona Bay 2	IKIP 0150, 0147	AA-44261, 44258	1007±29	974-800
Simushir	Nakotamori	KBP 2153c, 2153b	OS-67622, 67618	123±18	269-15
Simushir	Vodopadnaya 2	KBP 0561, 0567	OS-97891, 97892	2004±19	1995-1898
Simushir	Vodopadnaya 2	KBP 1825, 1830	OS-67470, 67472	1930±23	1926-1824
Simushir	Vodopadnaya 2	KBP 0563, 1013	OS-97890, 59204	1868±17	1869-1735
Simushir	Vodopadnaya 2	KBP 1827, 1460, 1391	OS-67587, 97905, 67420	1820±15	1815-1714

Simushir	Vodopadnaya 2	KBP 0576, 1474, 0584, 1536, 1550, 0581, 1831	OS-59346, 97906, 59203, 97997, 67586, 59201, 67492	1694±10	1683-1556
Simushir	Vodopadnaya 2	KBP 1454, 1402	OS-67269, 97904	1465±21	1389-1308
Simushir	Vodopadnaya 2	KBP 0487, 0574, 1231, 0483, 1329, 1826, 0582	OS-97889, 97893, 97900, 59421, 97903, 67471, 59202	1310±10	1289-1187
Simushir	Vodopadnaya 2	KBP 1565, 1246, 1530, 1832, 0479, 1534, 1237	OS-97998, 97902, 67616, 67588, 59381, 97907, 97901	1085±10	1051-957
Ushishir	Ryponkicha 1	KBP 0983, 0630	OS-59419, 59418	1114±19	1060-969
Rasshua	Rasshua 1	KBP 4007, 3507, 3600, 3586	OS-79601, 79722, 79726, 79724	969±13	930-800
Rasshua	Rasshua 1	pooled: KBP 3860, 3681, 3617, 3497, 4015, 3709, 4453, 4473, 4018, 4285	OS-79742, 98011, 79744, 79721, 79596, 98012, 98014, 98009, 79599, 79860	888±8	899-743
Rasshua	Rasshua 1	KBP 4106, 3996	OS-79667, 79896	2652±19	2782-2746
Rasshua	Rasshua 1	KBP 4136, 1899	OS-79604, 67086	2460±18	2705-2380
Rasshua	Rasshua 1	KBP 4105, 4103	OS-79666, 79720	2447±20	2699-2361
Rasshua	Rasshua 1	KBP 4017, 4155	OS-79598, 79859	2245±21	2336-2158

Rasshua	Rasshua 1	pooled: KBP 3650, 4102, 3839	OS-79863, 79671, 79868	2216±16	2313-2153
Rasshua	Rasshua 1	KBP 3721, 3947, 3935, 3943, 4137	OS-79727, 79729, 79731, 79730, 79664	215±13	299-0
Rasshua	Rasshua 1	KBP 4044, 4046	OS-80017, 80018	2105±18	2136-2004
Rasshua	Rasshua 1	KBP 4100, 4099, 3828, 3827, 3820, 3652	OS-79670, 79669, 79867, 79866, 79865, 79864	2055±11	2104-1951
Rasshua	Rasshua 1	KBP 4013, 4016, 4011, 4005	OS-79594, 79597, 79603, 79600	1952±14	1941-1869
Rasshua	Rasshua 1	KBP 4097, 3658, 3580	OS-79668, 79862, 79861	1916±15	1893-1823
Rasshua	Rasshua 1	KBP 4006, 3761	OS-80139, 79723	1107±29	1068-938
Rasshua	Rasshua 2	KBP 2130, 2129	OS-67136, 67135	1145±25	1174-976
Shiashkotan	Bashmak 2	KBP 3166, 3164, 3162a	OS-80021, 80023, 80022	325±15	457-310
Shiashkotan	Drobnyye 1	KBP 1666, 1665	OS-67479, 67443	2922±24	3160-2980
Shiashkotan	Drobnyye 1	KBP 1610, 0765, 0758	OS-79898, 59107, 59190	1507±18	1476-1341
Shiashkotan	Drobnyye 1	KBP 0715, 1642	OS-59036, 67413	1110±18	1058-968
Ekarma	Ekarma 1 [1]	KBP 3054, 3102, 3096, 3126, 3123	OS-79907, 79905, 79906, 79909, 79911	926±12	911-793
Ekarma	Ekarma 1 [1]	KBP 3125, 3062	OS-79910, 98103	1082±16	1053-937
Ekarma	Ekarma 1 [1]	KBP 3127, 3132	OS-98010, 79908	1006±16	960-915
Ekarma	Ekarma 2	KBP 3079, 3071	OS-79904, 79901	933±21	915-795

Chirinkotan	Chirinkotan 1	KBP 2074, 2073	OS-67088, 67087	943±19	922-796
Chirinkotan	Chirinkotan 1	KBP 2077, 2076	OS-67124, 67090	1614±19	1558-1415
Onekotan	Yagodnnyy North	KBP 3254, 3245	OS-80153, 80152	1030±19	965-925
Makanrushi	Bukhta Vostok	KBP 3436, 3437	OS-80029, 80030	1020±18	962-922
Makanrushi	Bukhta Zakat	KBP 3347a, 3339, 3342, 3341, 3333	OS-95662, 80115, 80117, 80116, 80114	912±12	907-787
Paramushir	Savushkina 2	KBP 0790, 0794	OS-93604, 93605	3745±18	4155-3994
Paramushir	Zerkalnaya	IKIP 0019, 0031	AA-40939, 40940	912±26	917-765
Shumshu	Baikova 1	KBP 0948, 0941	OS-59192, 59193	1990±25	1993-1887
1. Site Name: Ekarma 1 site, originally identified in 2006, was later treated as a new site during the 2007 excavations and labelled "Ekarma 3." These are the same site and samples from both years are labeled Ekarma 1 here.					
2. Calibration: Oxcal 4.2, IntCal13					

Figure 1

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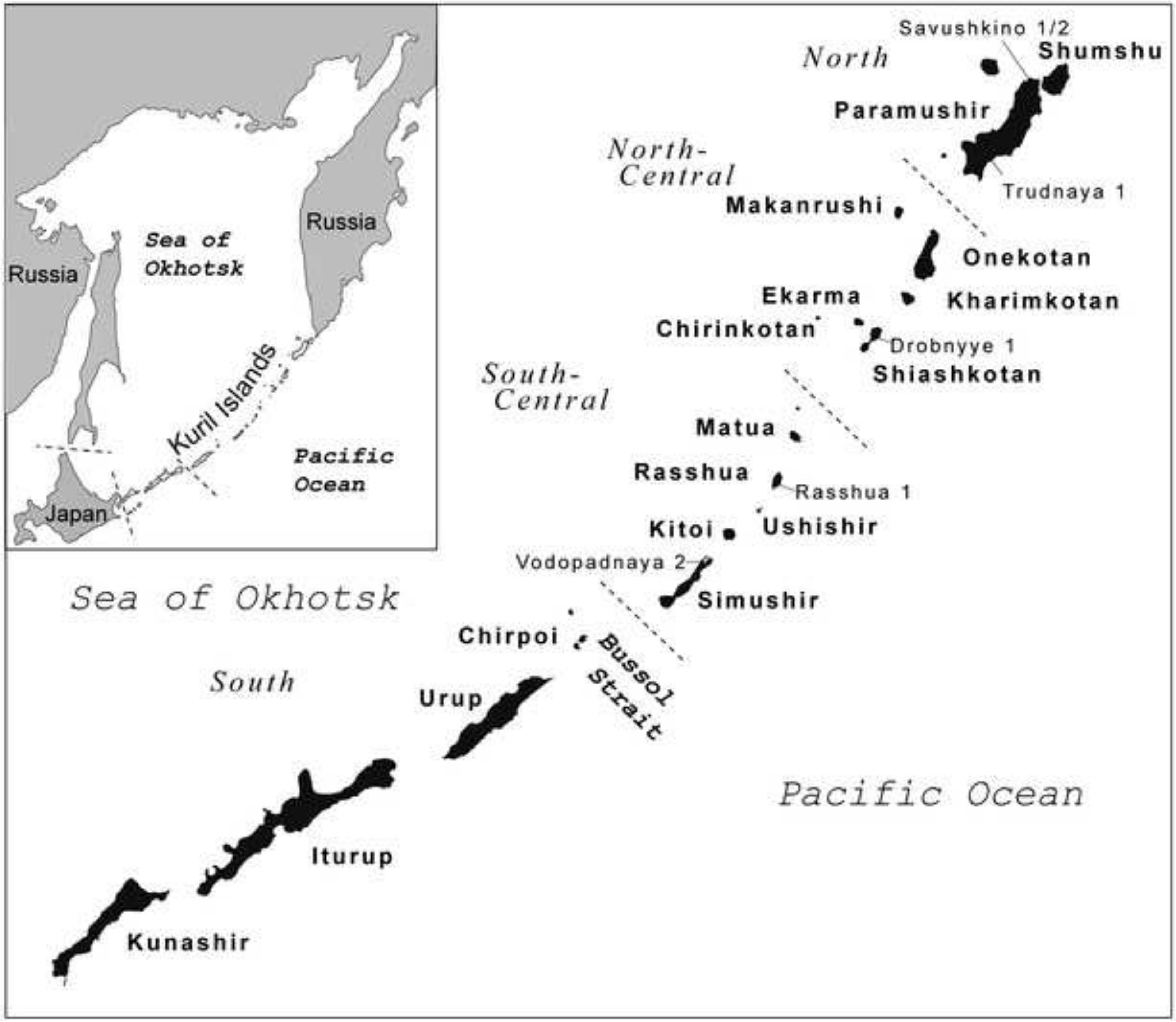

Figure 2 (color)

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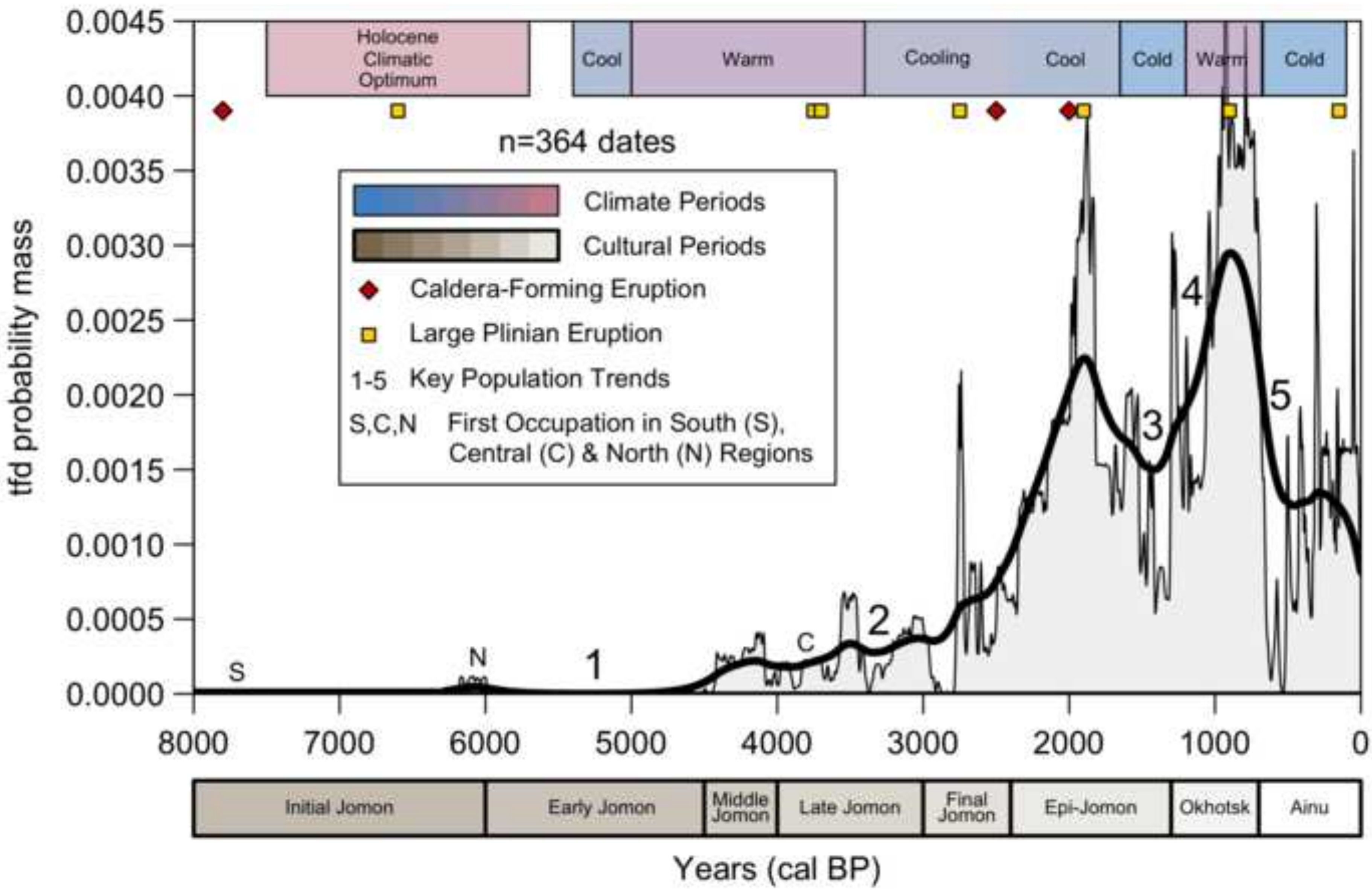

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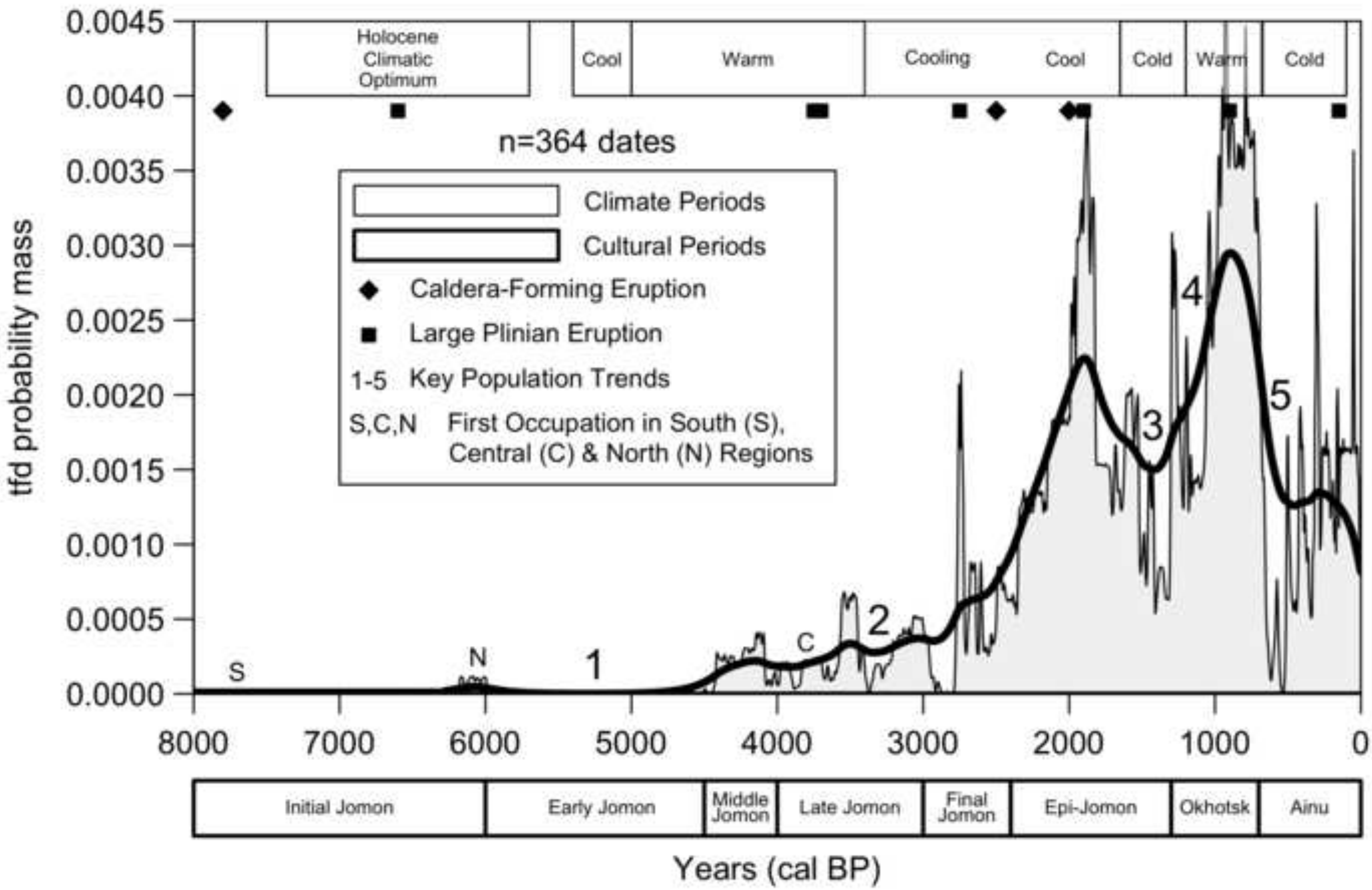

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Table 1 (380 records)

Table 1 in Fitzhugh, Gjesfjeld, Brown, and Hudson - paper submitted 9/15/15 to Quaternary International. Contact: fitzhugh@uw.edu

TABLE 1: Archaeological Radiocarbon Dates from the Kuril Islands (Kuril Biocomplexity Project [2006-2010] and International Kuril Island Project [2000])

Island	Site Name	Context[2]	Material[3]	Catalog #	Lab #	^{14}C age	95.4% Credible Interval (cal BP)[4]	Primary IKIP/KBP source[6]
Kunashir	Rikorda 1	Test Pit 1, Level 1, 0 - 28cmbs	Ch	KBP 0107	OS-58975	2250±25	2341-2158	C
Kunashir	Rikorda 1	Test Pit 1, Level 2	Ch	KBP 0115	OS-58967	2210±30	2320-2148	D
Kunashir	Serebryanoe 2	Erosion face: 35cmbs, 5 cm below Okhotsk pottery, 15 cm above Epi-Jomon pottery. Kun07-2 (Shubina and Samarin Survey)	Ch	KBP 2635	OS-67411	2440±30	2700-2357	E
Kunashir	Serebryanoe 2	Erosion face: 50-60cmbs, associated with Epi-Jomon pottery. Kun07-1 (Shubina and Samarin Survey)	Ch	KBP 2634	OS-67403	>Modern	n/a	E
Iturup	Berezovka 1	Erosion face, Profile 1, Level 2, hearth feature	Ch	KBP 0059	OS-93589	3290±25	3572-3456	E
Iturup	Berezovka 1	Erosion face, Profile 2, Level 11, charcoal sample #4, from south end of level	Ch	KBP 0083	OS-58748	2300±30	2356-2183	C
Iturup	Berezovka 1	Erosion face, Profile 2, 10 cm above hearth, charcoal sample #5	Ch	KBP 0084	OS-93593	2110±25	2146-2003	E
Iturup	Berezovka 1	Erosion face, Profile 2, Level 9A, charcoal sample #3, from north end of level	Ch	KBP 0082	OS-93592	2080±35	2144-1950	E
Iturup	Berezovka 1	Erosion face, Profile 2, 30-40 cm above hearth, charcoal sample #1	Ch	KBP 0080	OS-93590	2070±30	2123-1950	E
Iturup	Berezovka 1	Erosion face, Profile 2, Level 9B, charcoal sample #2, north end of level	Ch	KBP 0081	OS-93591	2030±30	2105-1898	E
Iturup	Glush	Test Pit 1 (erosion section), cultural layer, 56-80 cmbs - two layers mixed	Ch	KBP 0595	OS-93602	3640±25	4079-3875	E
Iturup	Kasatka Bay 1	Erosion face, 50-60 cm, associated with Middle Jomon pottery, basalt and obsidian: Itur07-2 (Shubina and Samarin Survey)	Ch	KBP 2637	OS-67417	3880±30	4416-4185	C
Iturup	Olya 1	Test Pit 2, 94 cmbs	Ch	KBP 0143	OS-93595	3820±25	4350-4096	E
Iturup	Olya 1	Test Pit 4, bottom cultural layer, Epi-Jomon	Ch	KBP 0139	OS-93594	2990±30	3323-3067	E
Iturup	Olya 1	Test Pit 3, Level 5	Ch	KBP 0152	OS-93597	1170±35	1180-981	E