IMPACTS OF EARTHQUAKE TSUNAMIS ON OREGON COASTAL POPULATIONS

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What were the impacts to human populations from great subduction earthquakes and resulting tsunamis? This key question has not been addressed by archaeologists. What happens to population growth curves along the northern California, Oregon, and southern Washington coasts when, on an average of every 572 years, a great-subduction earthquake (between 8 and 9+ on the Richter scale with up to 10 hours of tsunami waves) hits prehistoric settlements?

First, there must have been significant loss of life among the prehistoric populations. Second plant and animal resources would have been disturbed or destroyed to some degree. Third, communication and travel would have been disrupted. Fourth, water transport (canoes) on estuaries and along the coast would have been lost or destroyed. Fifth, shelters (housing) would have been lost or damaged.

If in mid-winter and at night, like the quake of 1700, people would have been in coastal winter villages. They must have faced massive damage when weather conditions were poor. Stored foods may have been lost or damaged. Sites on cliff edges (including winter houses) may have crashed into the sea.

PHYSICAL EVIDENCE

Adams (1992) summarized research into quakes in the Seattle area and found local tsunamis in the narrow channels, rock avalanches in the Olympic Mountains that dammed streams to produce lakes, and block landslides in Lake Washington. Atwater and Moore (1992) verified the local Puget Sound tsunamis north of Seattle. Karlin and Abella (1992) found steep basin landslides in Lake Washington in at least three locations that included large block slides that submerged forest habitats. Schuster et al. (1992) suggested that eleven rock avalanches in the southeastern Olympics were the result of quakes. "The rock avalanches that formed Jefferson, Lower Dry Bed, and Spider Lakes, and perhaps Lena Lake, provide evidence that strong shaking accompanied abrupt tectonic displacement in western Washington" (Schuster et al. 1992:1621). Logan and Walsh (1995) documented two drowned forests in lake Sammamish as evidence for one or two large block landslides into the lake as the result of a major earthquake.

So the physical damage from such events must have been massive. But the cultural and social damage must have been just as great. The loss of life in a small scale society would have a disproportionate effect on population growth curves, flattening them out, and modifying the region's demography. This in turn, would have long term effects on human ecology or popula-

Table 1. Twentieth Century Earthquakes, Locations, and Death Rates. (Source: Webster's Illustrated Encyclopedic Dictionary, De Vinne 1990).

Date	Place	Magnitude	Deaths
1906	San Francisco	8.3	700
1908	Italy	7.5	83,000
1920	China	8.6	180,000
1923	Japan	8.3	99,000
1927	China	8.3	200,000
1931	New Zealand	7.9	255
1935	Pakistan	7.5	40,000
1952	California	7.7	11
1963	Yugoslavia	6	1,000
1964	Alaska	8.5	178
1968	Iran	7.4	12,000
1970	Peru	7.7	60,000
1976	China	8	655,000
1976	China	7.8	240,000
1977	Iran	8	189
1978	Iran	7.7	15,000
1979	Ecuador	7.9	600
1980	Algeria	7.7	3,500
1980	Italy	7.2	3,000
1986	Mexico	7.8	5,550

tion adaptation. With the overall population being hit by periodic episodes of catastrophic death and destruction, there simply was a slower change in carrying capacity and a reduced need for changes in any of the key economic technological systems (production, distribution, consumption, or storage) or political systems (access to, and control over, important resources in the physical, biotic of cultural environmental context). Given population loss, there are fewer numbers to drive exponential increases in numbers over time. . .slowing down the standard growth rate over time.

The death rate must have been significant. It is impossible to know, but possible to model. Table 1 presents recent quakes and death rates.

Atwater's (1987) report on the rapid tectonic subsidence (.5 to 2 meters) of six intertidal peat layers over a 7,000 year interval, with tsunami sand overlays on three events, suggested great subduction earthquakes along the Juan de Fuca Plate flowing under the North American Plate. His conclusion was based on: 1) the rapid burial of the peaty layers; 2) the presence of tsunami deposited sands on three of the buried peat deposits; and 3) episodic tectonic subsidence could explain why tidal gage short term uplift rates are faster than long term uplift of marine terraces in the region.

Peterson et al. (1988) outlined a series of Holocene quakes and tsunami events at Netarts Bay. Cores indicated at least seven marsh burial events in the upper five meters and the first and third events were visible on cut banks. The greatest duration was on the order of 1000 years between event 4 and 5 while the shortest interval was about 100 years between 5 and 6. They concluded that the marshes must have dropped at least a meter to be buried by tidal flat mud. The sharp contacts above five of these indicated very abrupt burial and four record catastrophic sheetfloods.

> Major subduction earthquakes take place in the Northwest every few hundred years, at which time abrupt subsidence of the coast reverses the gradual seismic uplift that accompanies the accumulation of strain. There is evidence at Bandon for significant wave-induced cliff erosion in the past, but a general absence within historic times. We suggest that the cliff erosion occurred some 300 to 500 years ago following the last major earthquake, but that subsequent uplift has resulted in the progressive decline and eventual cessation of cliff attack by waves.
>
> . . . recent evidence suggests that there have been major prehistoric earthquakes resulting from the long-term accumulation of strain. This evidence has come from investigations of estuarine marsh sediments buried by sand layers, deposits which suggest that during prehistoric times portions of the coast have abruptly subsided, generating extreme tsunami that swept over the area to deposit the sand. Based on the numbers of such layers at Willapa Bay, Washington, and Netarts Bay, Oregon, it has been estimated that catastrophic earthquakes and land-level changes have occurred at least six times in the last 4,000 years at intervals ranging from 300 to 1,000 years. The last recorded event took place between 300 and 500 years ago. Therefore, strong evidence exists that major subduction earthquakes do occur along the Northwest coast, but with long periods of inactivity between events" (Komar et al. 1991:14, 20).

The work at Netarts Bay by Darienzo and Peterson (1990) recorded six episodic events. Five had sharp non-erosional upper contact surfaces covered either with tsunami sands or tidal flat muds. The lower marsh contacts show slow gradual uplifts on the order of 0.5 to 1.5 meters, interspaced with sharp episodic subsidence of 1 to 1.5 meters. The intervals ranged from 300 to 1000 years and the last event was dated 300 – 400 Radiocarbon Years Before Present (RCYBP). The events were roughly 400, 1220, 1600, 1700, 3000 and 3300 years ago.

Darienzo and Peterson (1995) summarized the data on the number, sequence, magnitude and event synchroneity for earthquakes based on radiocarbon dates and dendrochronology.

Given the ranges in absolute dating methods, synchroneity could only be inferred and not proven. The magnitude was estimated from equations based on the area of rupture, amount of slip and the shear modulus. The latter was based on the 1964 Alaskan and 1960 Chilean subduction zone quakes.

> In this study, we used radiocarbon ages of samples taken from the stratigraphic record of earthquakes in seven estuaries on the northern Oregon coast to calculate average recurrence intervals for Holocene earthquakes in the last 3,000 years . . . In calculating the average recurrence for each estuary, we used only the last six inferred earthquakes in each estuary, because the preservation potential of buried peat deposits diminishes over time, due in part, to erosion by migrating tidal and river channels. The age of the youngest peat was subtracted from the age of the oldest buried peat and divided by the number of intervals between the oldest and youngest events (Darienzo and Peterson 1995:5).

Darienzo and Peterson concluded that the data clearly demonstrated that there was a consistency in depth and number between the events along the northern coast. The variation was due to local geomorphic and geological differences. The range of radiocarbon data was fairly consistent for some events and more variable for others, and some peat deposits have not been dated at specific locations (Figure 1).

> Based solely on radiocarbon dating, past subduction-zone earthquakes along the northern Oregon coast could have been either subduction-zone earthquakes that occurred synchronously among all estuaries on the northern Oregon coast or subduction-zone earthquakes that occurred among estuaries within two or more segments. Nevertheless, the radiocarbon dating shows that a similar number of earthquakes occurred within similar time intervals throughout the northern Oregon coast (Darienzo & Peterson 1995:8).

Three to five tsunami events were also found in the data. Three of the tsunami events in the three northernmost estuaries do not lie on top of buried peat as there was no subsidence at those locations. The tsunami sands also support event synchroneity so they concluded that there were at least four and perhaps five coseismic subsidence subduction-zone earthquakes in the last 3,000 years. Events 1, 3, and 6 were between magnitude 8.9 and 8.0, depending on rupture length. There were at least six and perhaps seven events (Event #0) (see Figure 1).

> The average recurrence interval for each estuary falls between 200 and 600 years (to the nearest 50 years). One exception is in averaging the last five events at Yaquina Bay, which increased the upper value in the range to 650 years. . . .The average interval range (350-700 years) for South Slough, a southern Oregon estuary included for comparison, is relatively consistent with these results (Darienzo and Peterson 1995:10).

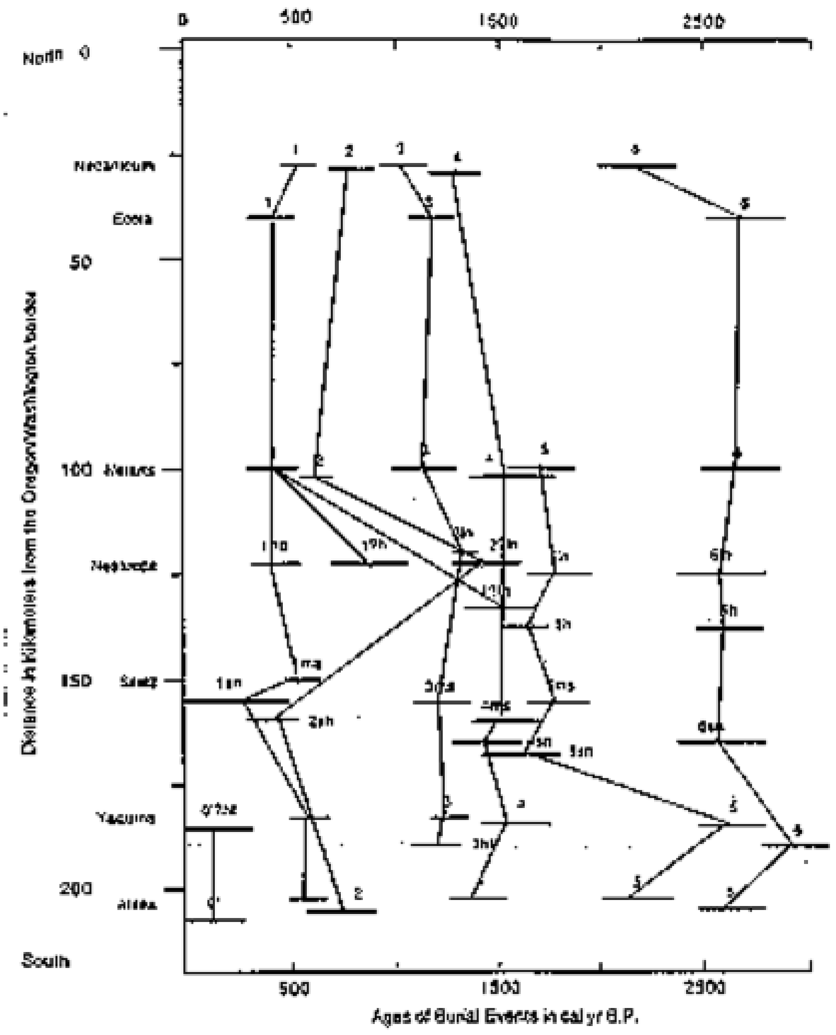

Figure 1. Radiocarbon Dates, calendar years B.P. for the Necanicum, Ecola, Netarts, Nestucca, Siletz, Yaquina, and Alsea estuaries (from Darienzo and Peterson 1995:9).

Atwater (1997) summarized the data for great (magnitude 8 or greater) subduction quakes and related tsunamis for coastal Washington. His evidence applies to Oregon as well. Sequences of marsh and forest soils that were above tidal zones and then dropped below tidal zones by these quakes have been discovered.

Atwater notes that regional lowering of landforms is common in great subduction quakes. Buried lowlands have been recorded in the lower Copalis River, Grays Harbor, Willapa Bay and the lower Columbia River marked by standing dead trunks of western red cedar. These trees died about AD 1700.

> The spruce stumps and *T. maritime* rhizomes thus suggest that the land was lowered at least ½ to 1½ m relative to the sea. In comparison, the subsidence from great subduction-zone earthquakes in Alaska and Chile caused as much as 2 m of widespread coastal submergence (Atwater 1997:82).

This event was sudden, and not a gradual change. "Herbaceous plants rooted in some buried lowland soils retain stems and leaves that are entombed in overlying tideflat mud" (Atwater 1997:84).

> Some of the buried coastal soils in southern Washington and northern Oregon are mantled with sandy deposits probably left by tsunamis. Such deposits widely overlie the youngest buried soil .... The sand records an unusual event; relative to other sand above the soil, it is exceptionally coarse or thick or both. During the event, the sand moved landward, the direction in which sand tapers. . . . Deposition of the sand was interrupted by lulls during which mud settled . . . . Deposition approximately coincided with sudden subsidence of the land, for the sandy interval surrounds rooted tufts of grass that lived on the soil at the time of subsidence . . . . Extraordinary, landward directed, interrupted by lulls, and approximately coinciding with coastal subsidence in Washington, deposition of the sand is not easily credited to a flood or storm, or to a tsunami of remote origin. Rather, the sand implies a tsunami from an earthquake at the Cascadia subduction zone (Atwater 1997:87).

In discussions with Tom Connolly (personal communication 2001), he has pointed out that the local changes did not fundamentally change the land-sea relationships any where near the impacts of sea level rise due to the melting of the Pleistocene glaciers. While true, sea levels essentially stabilized about 3500 years ago, from which the 4000 year earthquake data overlaps slightly. The coastal drowning of river valleys, formations of estuaries and sea level changes had a major impact on erosion of earlier sites. This is reflected in the data on sites found later in this paper.

ARCHAEOLOGICAL EVIDENCE

Thomas Newman's excavation at 35-TI-1 resulted in the following observation:

> The interesting relationship of the Lowest Occupation and the present sea level and fresh water table suggests that the sand spit on which the site is located has changed in appearance within the last five or more centuries. The lowest occupation rests on sand, sterile to some depth, water not permitting extensive additional testing. There is some suggestion that this may have been a beach, considering the slope of the occupation and the appearance of the sand underneath which looked very much like the present beach sand. If this occupation was located on a beach, the marshy area intervening between the site and the bay would not have existed. The surface of the marsh is well above the Lowest Occupation and has certainly been elevated, if not formed, subsequent to the time of occupation. If, as suggested previously, the Lower Occupation should have stood a meter above sea level for comfort of the occupants, an examination of changes in sea level during the past few centuries may be in order (Newman 1959:35).
>
> Drucker (1943) notes that several middens discovered during his survey of the northern Northwest Coast were being eroded by the ocean. The base of the middens were covered by high tides. This suggests that it may not be purely local subsidence of land which is responsible for inundation of sites, but the general phenomenon of eustatic adjustment as well (Newman 1959:35 – 36).

Emory Strong (1973), an engineer and "avocational archaeologist" wrote an article about land subsidence in *The Ore Bin*:

> I first became aware of this geological phenomena while searching the banks of the Columbia River for Indian artifacts. I located all of the old villages in the Portland vicinity and, when the spring flood waters were receding, hunted as I could in my boat to see what prizes erosion had uncovered. Most of the sites were completely submerged by even a normal freshet, and in order to rescue relics before they washed away (or before someone else got them) I kept a record of the normal river stage for the first and subsequent visits.
>
> The flooded sites puzzled me. There seemed to be no acceptable reason to have a village where every spring it must be abandoned. The Indians built their houses of planks, fashioned with great labor, over a pit 3 or 4 feet deep, so it is doubtful they would have built on flood-prone land, had they done so, they would have had to remove the valuable planks before the flood and afterwards clean the pit of silt before rebuilding their houses. Although most sites show occasional flooding, the stratification indicates a time interval of centuries (Strong 1973:109 – 110).

He notes that: 1) Shoto Village, which was dug by the Oregon Archaeological Society from 1964 – 1966, hit submerged midden; 2) a 1971 University of Washington excavation on

Lake River ran into submerged deposits; 3) Drucker (1938:110) recorded submerged sites in a 1938 survey and thought "there might have been sudden submergence of the area; 4) Dougherty (WSU) in response to Strong's inquiry, noted a number of recently submerged sites; 5) Gibbs published Indian myths about earthquakes; 6) Mead notes rock art below tide levels; 7) Newman's excavations on the Tillamook Spit noting water problems (*noted above)*.

Minor (et. al 1989) examined the relationship between the deposits and C^{14} dates for the North Yaquina Head site (35-LNC-50) (Figure 2). He found that his oldest date predated events, his single date for the non-shell occupation fell into the period between the 3rd and 2nd buried marsh, and his six dates for the shell midden deposits fell between the 2nd and 1st buried marshes.

> The temporal distribution of the six radiocarbon dates from the shell-bearing strata thus seem to indicate that deposition of the shell midden at 35LNC50 correlated with a period of relative stability in between these last two subsidence events. Occupation was discontinued sometime after 550 ± 60 BP, a date that is sufficiently close to the age of the first subsidence event at 370 ± 60 BP to suggest that the site may have been abandoned as a result of a change in the local coastal environment resulting from an earthquake.
>
> Evidence of such environmental change may be represented by the relatively frequent occurrence of butter and littleneck clams at 35LNC49 and 35LNC50. As noted in Chapter 4, these species prefer the calm water of bays and estuaries, but they can also be found in protected settings along the outer coast. Their relative frequency in the middens strongly suggests that during the period these sites were occupied these molluscan species were available locally, most likely below the sites in the small cove formed by the westward extension of Yaquina Head. As a result of subsidence associated with the most recent earthquake, relative sea level may have risen and changed the molluscan habitats below the sites, accounting for the fact that these species of clams are only rarely found along the shores of Yaquina Head at the present time. The situation at 35LNC50 thus suggests that archaeological evidence from shell middens may have an important role to play in documenting the occurrence and significance of prehistoric earthquakes along the Oregon coast .... (Minor et al. 1989:77).

Woodward et al. (1990) report on excavation sat the Wilson River site (35-TI-2) and the Nehalem Bay site (35-TI-4). At the former site:

> Yet, while there is no direct support for earthquake-generated catastrophic change at this locality, the abrupt disappearance in shellfish utilization can be interpreted as indicating that the rapid habitat change resulted from the periodic building and breaching of the sand spit protecting Tillamook Bay. That beaching and disappearing of the sand spit could have been caused by wave erosion from tsunamis and/or bay sieching (Woodward et al. 1990:61).

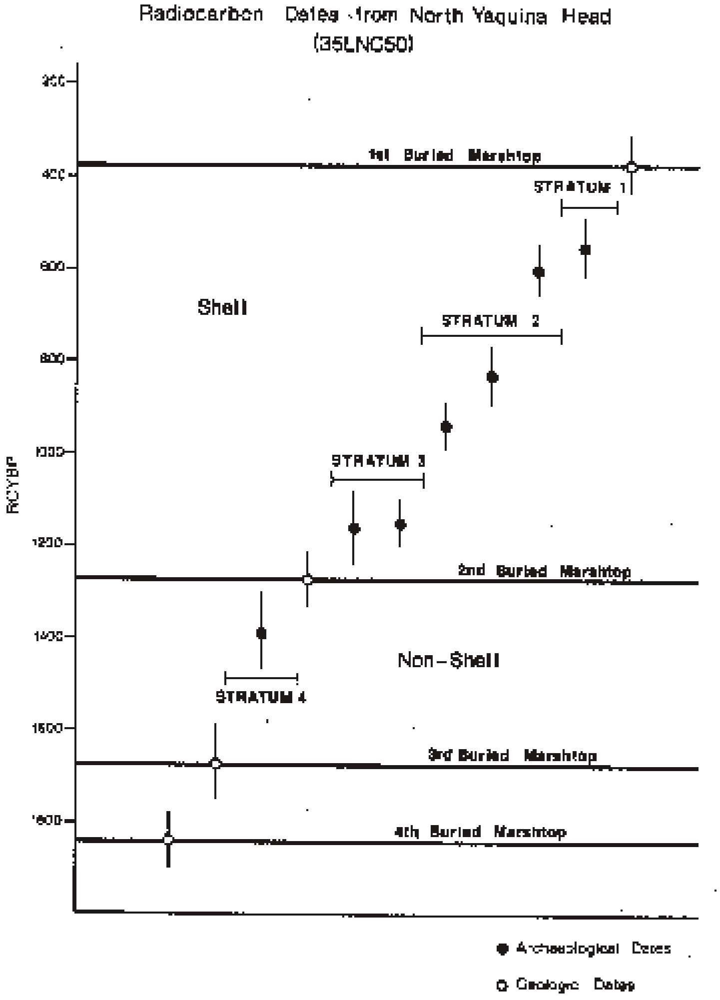

Figure 2. Relationship between archaeological deposits and C^{14} dates for the North Yaquina Head site (35-LNC-50) (from Minor et al. 1989:76).

The oldest documented archaeological site of the group of sites at Nehalem Bay (Site 35-TI-4) is fully inundated and consists of a layer of fire-cracked rock overlain by a 35-cm-thick stratum of silt.... The upper 10 cm of the silt include waterlogged organic materials containing leaves of willow *(Salix* sp.), and red alder *(Alnus rubra)*. Also present is moss (*Sphagnum* sp.), a cone of red cedar (*Thicka plicata*), and numerous seeds of Sitka spruce (*Picea sitchensis*). Wood fragments and small logs also occur at the top of the silt and include Douglas fir (*Psudotsuga menziesii*). These plants are found around Nehalem Bay at forested wetland margins located at present no closer than 0.9 km from this site. Fragments of a waterlogged twinned mat woven from Douglas fir root were found

> at the top of the silt. A portion of the mat has been radiocarbon dated to 380±60 years B.P., with a calibrated range of A.D. 1410-1635 (Woodward 1986). This date is consistent with the radiocarbon date of 370±60 years B.P., with a calibration range of A.D. 1431-1660, obtained from the top of the buried marsh at Netarts (Peterson et al. 1988). The silt layer is interpreted as having formed in a sheltered tidal marsh that developed behind a prehistoric sand spit. Sand dunes bordering this marsh stabilized and were invaded by a dense growth of Sitka spruce, willows, red alder, and shrubs, creating a spruce swamp/tidal channel habitat. Leaves and other vegetation fell, were washed directly into a body of quite shallow water, and there covered with silt. This phase ended abruptly between 300 and 400 years ago with the disappearance of the sand spit and burial of the spruce swamp with wave-transported sand. This was a potentially catastrophic event for any prehistoric community at this location. More recently, channel shifts have cut into the deposits and exposed the edge of the site (Woodward et al. 1990:61 – 62).

Minor's (et al. 1991) abstract for the excavation at the Nehalem Bay Dune site (35-TI-57) states that:

> Five radiocarbon dates from the cultural deposits range from 640 ± 60 RCYBP to 340 ± RCYBP, indicating use of areas sampled during this project over a span of about 300 years, from A.D. 1320 to A.D. 1610. A sixth date of 630 ± 50 RCYBP: A.D. 1320 was obtained from a black sand layer underlying the site's southern margin. The earliest dates from this are coeval with the age of a "buried peat" on Netarts Bay that may represent evidence of an earthquake. If confirmed through further research, occupation at the Nehalem Bay Dune site would thus have begun immediately after this significant geological event (Minor et al. 1991:iii).

Jones (1991), in response to theories that coastal resources are second-rate concluded that such resources were attractive and valued and that:

> The early archaeological record of coastal California reveals no single pattern. Superficially, at least, initial occupation of the coast appears to vary with latitude and type of coastline. Estuaries generally were occupied earlier than some open coasts, except in southern California where the earliest human settlers used semiprotected rocky coasts and islands as well. As Erlandson (1988a) points out, these early southern California coastal sites refute the theories that portray coastal habitats as unattractive. In central California, however, early inhabitants used inland lakes and estuaries, but not open coasts until ca. 4000 B.C. An even greater delay in the use of marine habitats is evident north of San Francisco Bay, where there is almost no evidence of human presence in the coastal zone prior to 500 B.C. (Jones 1991:429).

The impact of periodic earthquake/tsunami events on human populations, as well as impacts on resources, is an important explanatory variable in cultural ecology and population adaptation. In addition, smaller estuaries are, in many cases, late developments. They were small deep cut canyons that flooded with sea level rise. The deposited sediments that built up estuarine systems, in turn provided habitat for shellfish. The age of estuarine systems must be included in any interpretive models.

Connolly, did limited testing at the Palmrose site (35-CLT-47) and Avenue Q site (35-CLT-13). The former was occupied from about 4000 to 1500 years ago and the latter occupation spanned 3300 to 1000 years before present. The two sites fall into the area where evidence for six subsidence events have been documented.

> There is no demonstrable direct link between subsidence events and changes in human occupation in the project area, although such a relationship is possible. Abrupt subsidence, and accompanying severe earthquakes, may have triggered slides on Tillamook Head, and may have altered deposition patterns in the southern Clatsop Plains region.
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> Darienzo (1991; Darienzo and Peterson 1990) records one of a series of subsidence events at Netarts Bay at about 1700 radiocarbon years ago, roughly the time of abandonment of the Palmrose site and possibly the beginning of the most intense occupation at the Avenue Q and Par-tee sites. This event appears to be contemporaneous with an undated subsidence event at Seaside (buried marsh #5). Another subsidence event at approximately 1100 radiocarbon years ago may have precipitated abandonment of Avenue Q and Par-tee sites. However, this is also approximately the time of significant oceanward dune migration in the project area. Rankin (1983) notes that prior to 1100 years ago dune-building was most dramatic along the northern Clatsop Plains, but after this time accelerated along the central and southern Clatsop Plains. Abandonment of the Avenue Q and Par-tee sites appears to coincide with increased dune development, and seaward migration of the beach front at this time (Connolly 1992:170 – 171).
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> Larson noted the following:
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> The shellfish appear to be hardy even in the face of upheaval such as the tsunami and the subsequent three foot submersion of the West Point landform. Pam Ford (Appendix 6) examined the pre- and post-earthquake sizes of three taxa, horse clam, butter clam, and native littleneck clam, to determine the effects of the earthquake on the shellfish population at West Point. If there had been changes in individual animal sizes as a result of population adjustments to the seismic induced alterations in the intertidal zone, there should have been differences in the size of pre- and post-earthquake groups. Ford (Appendix 6:25) saw no differences in animal size (Larson 1995:13–18).

Roberta Hall's work at 35-CS-43 investigated tsunami events in core samples. In 1990, two large and very fragile unfired clay bowl-shaped objects were recovered in deposits that suggested they had been buried by a 30 cm thick sand layer that had preserved them. Hall believed the deposits were tsunami caused. The top 50 cm of the site was too badly disturbed for event preservation. She recovered two C^{14} dates:

> Dates from Bradley Lake, 5 km south of the Coquille estuary, suggests subsidence episodes at approximately 300, 1,000 and 1,600 years ago (Nelson et al. 1994). Because our date from Core 4 is based on bulk material above the flood deposit bed, we infer that the flood recorded in Core 4 occurred before 1,250 years ago and thus could refer to the subsidence event of 1,600 years ago at Bradley Lake. The flood deposit evident from Core 5 precedes recorded subsidence events and offers a line of study for geologists in nearby areas. While these results are suggestive, they are far from conclusive (Hall 1995:20).

Minor (1996) presented a paper on the implications of earthquakes on Northwest Coast archaeology at the 61st Society for American Archaeology Conference:

> Direct evidence for earthquake-induced submergence and burial of archaeological sites has been found on the Salmon and Nehalem Rivers on the northern Oregon coast. The clearest example was at 35LNC64 on the Salmon River, where fire-cracked rocks and pieces of flaked stone are exposed at low tide for 180 m along the base of the riverbank. Remnants of several hearths were observed at the base of the buried soil, which caps a former sand dune complex. Charcoal from one of these hearths yielded a radiocarbon age of 470 ± 60 B.P. (Beta-27876). A peat sample from the uppermost several centimeters of the buried soil yielded a radiocarbon date of 370 ± 80 B.P. (Beta 27877) (Minor 1996:5).

Minor contrasts the long shell midden sequences in Alaska, British Columbia in the north, and southern California to the south to the relatively late shell midden occupations in the Pacific Northwest region (only 10 sites older then 3,000 years and a maximum of 5,100 years for shell midden deposits). He suggests that the absent middens may relate to some factor in site preservation related to episodic subsidence. And, in an informal discussion, he also brought up the relatively shallow midden deposits for this area in comparison to shell midden deposits to the north and south.

Minor and Grant (1996) concluded that:

> Aside from direct inundation of prehistoric settlements, abrupt subsidence of the shoreline may have affected prehistoric coastal populations by altering landforms (e.g., bays, spits, and river mouths). Abrupt changes in shoreline elevation may have disrupted the distribution of marine shellfish and sea mammals, resources on which coastal peoples depended to a considerable degree. In this regard, several recent studies have inferred a possible connection between the timing of prehistoric earthquakes (as reflected in marsh subsidence events) and abrupt changes in marine resource exploitation and settlement patterns at archaeological sites along the Oregon coast (Minor and Grant 1996:777).

Cole (et al. 1996) outlined evidence from two archaeological deposits found buried in peat and tsunami layers. The Copalis River Site (45-GH-104) was exposed by erosion of Cedar Creek in a buried subsidence peaty layer dated to the 1700 event. The Niawiakum site (45-PC-102) was in the uppermost of six buried peaty horizons exposed at extreme low tides. They concluded that the 1700 earthquake and tsunami event buried these two sites, and that more sites may be in buried contexts, thus creating a survey bias in the archaeological record.

> Seismic activity about A.D. 1700 at the Cascadia subduction zone caused submergence, tsunami inundation, and consequential burial and tidal flooding of low-lying coastal sites that native peoples occupied during previous centuries. This may help to explain why relatively few prehistoric sites are known from a region whose rich microenvironments supported a large prehistoric population in early historic times. Many prehistoric sites along the coast were probably permanently inundated by Holocene sea-level rise; others have no doubt been destroyed by waves and migrating channels; still others may lie beneath dense forest vegetation that impedes survey. The history of the Copalis and Niawiakum sites shows yet another way in which cultural materials may remain undiscovered: estuarine burial resulting from earthquake-induced lowering of coastal land (Cole et al. 1996:173–174).

I suggest in this paper that the periodic earthquakes and tsunami events had a major impact on population growth in northern California, Oregon, and southern Oregon. As a result, there were simply fewer people here throughout the prehistory of the region. In turn, there are fewer sites and sites of less depth. In addition, since 50% of the currently recorded sites are below the tsunami runup zone, a significant percentage may have been destroyed or buried. This may be especially true because of their relatively small size and shallow depth. The impacts to cultural development must have been great, as a significant portion of the population is lost, and the landforms and resources changed in their relative location, predictability, and abundance.

Hildebrandt and Levulett also try to address the missing sites in the archaeological record for the northern California coast. The earliest sites date in the 3000 – 2000 RCYBP period and are relatively small shallow shell middens or sites. "Only by 1500 RCYBP, residential use becomes relatively common. . .and by about 1000 RCYBP intensive exploitation of coastal resources is clearly documented by the abundant presence of sedentary villages, as well as the widespread use of oceangoing canoes" (Hildebrandt and Levulett 1996:3). They also conclude that "the antiquity of marine resource use should increase as one moves north into Oregon, Washington, and Canada" (Hildebrandt and Levulett 1996:14). They felt the Sitka spruce forests and tundra would have fewer terrestrial resource values, encouraging marine resource use.

Hutchinson and McMillan (1997) summarized radiocarbon dates and stratigraphic evidence for earthquake and tsunami impacts to sites in the Nootka, Barkley, and Olympic areas in Washington:

> The hypothesis that prehistoric great earthquakes at the Cascadia subduction zone affected native peoples is supported at many sites by the presence of inferred tsunami deposits or other noncultural layers in midden stratigraphy and by fluctuations in site activity levels based on the distribution of radiocarbon ages. Some sites (such as Yuqout) appear to have gone through a cycle of abandonment and reoccupation following each major earthquake. In other cases (such as Hesquiat Rockshelter DiSo9), the site was reoccupied after one great earthquake,

> but was permanently abandoned following a later event. Clusters of nearby sites showing sequential occupation (such as Lower Sand Point, Cedar Creek, Ozette, and White Rock on the outer Olympic Peninsula) may indicate village relocations following catastrophic events.
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> The impact of individual events on site occupations may not have been uniform. Variability in site impact may reflect differences in the magnitude of events or the location of rupture areas on the plate interface (Hutchinson & McMillan 1997:85–86).

In the final nomination document for archaeological sites within Oregon Parks & Recreation Coastal Parks, Erlandson & Moss (1997) observe:

> Our research has shown that over 87% of the radiocarbon dates from archaeological sites on State lands of the Oregon Coast fall within the last 1500 calendar years. Nonetheless, recent research has also identified several Early and Middle Holocene coastal sites on coastal State parks lands: the 8600 year old 35-CU-67 at Indian Sands (Moss & Erlandson 1995b, 1995c); 8300 and 5000 year old components at 36-CU-75 at Blacklock Point (Minor 1993; Moss and Erlandson 1995a: 103); a 6100 year old component at 35-CU-82 near Cape Blanco (Minor and Greenspan 1991; Moss and Erlandson 1995a: 103); and the 4200 year old 35-LNC-45 at Boiler Bay (Tasa and Connolly 1995). Only the Indian Sands and Boiler Bay sites contain the remains of marine foods. The other two sites produced no faunal remains, but are currently located adjacent to productive coastal habitats. Recent investigations at these and other Oregon Coast sites suggest that coastal subsidence played a significant role in Early and Middle Holocene economies in the area. Although this early use of marine resources may have been less intense than in other areas of the Pacific Coast (Erlandson and Moss 1997:12–13).

And finally, Scott Byram sums up my opinion nicely:

> The massive earthquake of 1700 A.D. occurred along the entire Oregon coast and large regions to the north and south. Coquille communities were affected by the earthquake, as were the Tillamooks, Makahs, Yuroks, and many other tribes. We don't know how severely the Coquille people were affected by this event, but villages located along the estuary shore would have been devastated. Afterwards, the survivors from the shoreline villages may have sought refuge with friends and relatives living inland, but even there the effects of the earthquake must have been great. We know that eventually the survivors rebuilt their villages by the estuary shore, and fishing weirs were moved to adjust to changing tidelands and fish habitat. By the late 1800's the earthquake and tsunami flood were distant memories shared in a few stories told around the hearth in winter (Byram 1999:4).

In discussing these issues with Scott Byram, he mentioned the idea that earthquake and tsunami events should be looked at in terms of population intrusions into coastal environments. That these events may have created a kind of cultural vacuum due to lowered population densit-

Table 2. Population size for Oregon Coastal Groups before 1774 (From Boyd 1990:136).

GROUP	Mooney, 1928	Boyd, 1990
Chinook & Clatsop	1100	1260
Tillamook	1500	4320
Alsea	6000	3060
Siuslaw	0	2100
Coos	2000	2250
Tututni & Chetco	3600	4500
TOTAL	14200	17490

ies, allowing groups to move into territory previously occupied by stronger and larger populations. This is an interesting testable hypothesis.

COASTAL POPULATIONS

The groups along the Oregon coast at contact, from north to south, were the Chinook, Tillamook, Alsea, Siuslaw, Coos, and Athapaskan Tututni. Boyd, in the *Handbook of North American Indians* (Vol 7), notes the before 1774 there were about 200,000 people in the Nothwest culture area that includes coastal Oregon. His calculations for population size for Oregon groups are presented in Table 2.

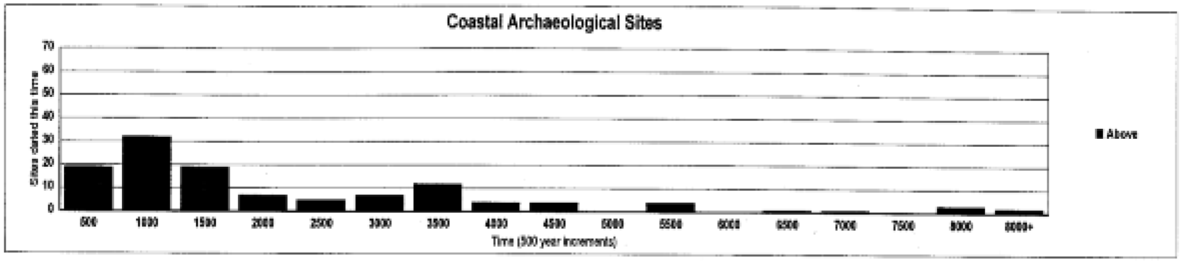
Mooney's total for Alsea and Siuslaw were combined. Seaburg and Miller (1990:561) list population estimates for the Tillamook: Lewis & Clark at 1,000 in 1805 – 1806; a Hudson's Bay Company estimate of 1,500 in 1838, but that included some Alsea and Siuslaw. Zenk (1990a:570) indicated a population for the Alsea at 1,700 based on Lewis & Clark in 1806. Zenk (1990b:578) also gave an estimate for 1806 of 900 Siuslaws (proper), from 500 to 1,700 Lower Umpquas, and 1,500 Coosans.

Given Boyd's total, a great subduction earthquake and tsunami death rate of 1% would be 175 people; 5% would be 875 people; 25% would be 4373; and 50% would be 8745 dead. Since 208 (50%) of the recorded 417 archaeological sites in Oregon are below the George Priest tsunami runup lines for such quakes, and 97 (23%) were too close to call, the loss of life among prehistoric populations from such events may have been very high. If the "too close to call" are added to the "below", there are 305 (73%) sites at risk.

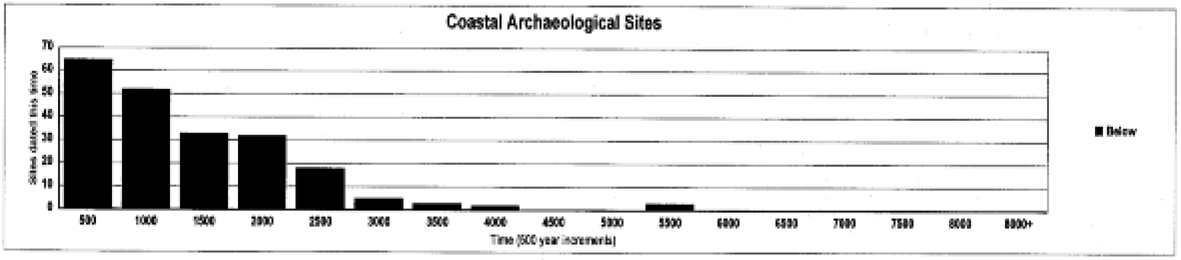
The dates on existing sites are interesting by themselves. The essentially exponential line for the sites below the tsunami zone could represent a number of things. It could reflect simple

500 = 0-500 years ago; 1000 = 501-1000 years ago; etc.
Above = above tsunami run-up line; Below = below tsunami zone; On = too close to call.

	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8000+
Above	19	32	19	7	5	7	12	4	4	0	4	0	1	1	0	3	2



	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8000+
Below	65	52	33	32	18	5	3	2	0	0	3	0	0	0	0	0	0



	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8000+
On	15	18	10	0	2	2	0	0	0	0	0	0	0	0	0	0	0

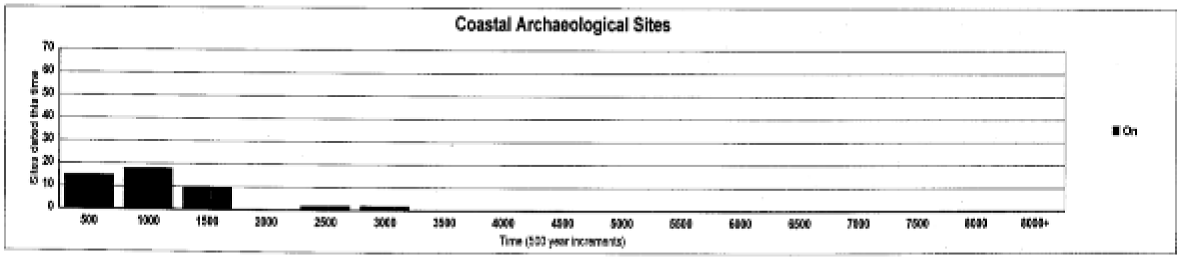


Figure 3. Sites Above, Below and On Oregon Coast tsunami run-up lines.

population growth over time. It may also reflect differential preservation of sites as sea levels rose and stabilized roughly 3000 years ago. Perhaps it reflects differential preservation of sites in relation to earthquakes and tsunamis. It may simply be a sampling related artifact and may not be "real."

The sites above the tsunami run-up zone have faint four part clusters. One about 1000 years ago, another around 3500 years ago, the next at 5500 years ago, and the last at 8000 years ago. The numbers of dates for sites above the tsunami line greater than 3000 years ago (31) is over twice the number for sites below (13) and on (2) the run-up line (Figure 3).

This suggests that there may be differential preservation. But this depends on other factors like sampling. It can only be "suggestive" until tested rigorously with methods to reduce sampling error. As noted earlier, the effects of sea level change and erosion must also be factored into the differences in dates between sites above the tsunami zone and those below.

DEMOGRAPHIC MODEL

Elizabeth Housworth, with the Mathematics Department at the University of Oregon helped me prepare some simplistic models for the demographic impacts of regular population loss. In order to make the models, very simple assumptions were made. There is no data from which to estimate population sizes and densities through time for the research area. We simply do not have enough data to make any assumptions. Given the limitations, a very simplified set of assumptions were used to generate the comparative curves:

1) The curves were set up for a small initial population of 100 people within a localized geographic area, perhaps something like a pocket beach community between two headlands.

2) The curves were run for a 4000 year period using the average great subduction quake period as 572 years.

3) The population growth rate was set at 0.1% throughout the models.

4) A death rate of zero, 1%, 5%, 10%, 25%, 40% and 50% were then projected. The latter was set as the limit as it produced a negative curve (Figures 4 and 5).

The seven curves are self explanatory. The zero impact result is a population of about 6000 people over the 4000 years. Within the parameters of the models, a 1% death rate reduces population size by 1000 people over 4000 years. The 10% death rate cuts the population size in half within this model. The 25% rate keeps the population very flat, a growth from 100 to about 1000 in 4000 years. The 40% impact only doubles the population in 4000 years and the 50% rate actually decreases to population from 100 to about 80 people in 4000 years. While the numbers are simple extrapolations from the set of assumptions, the models still give both a visual feeling for the impact of periodic events that can cause population loss.

Our exponential growth model assumes a theoretical initial population of size 100 and a theoretical growth rate of 0.1%.

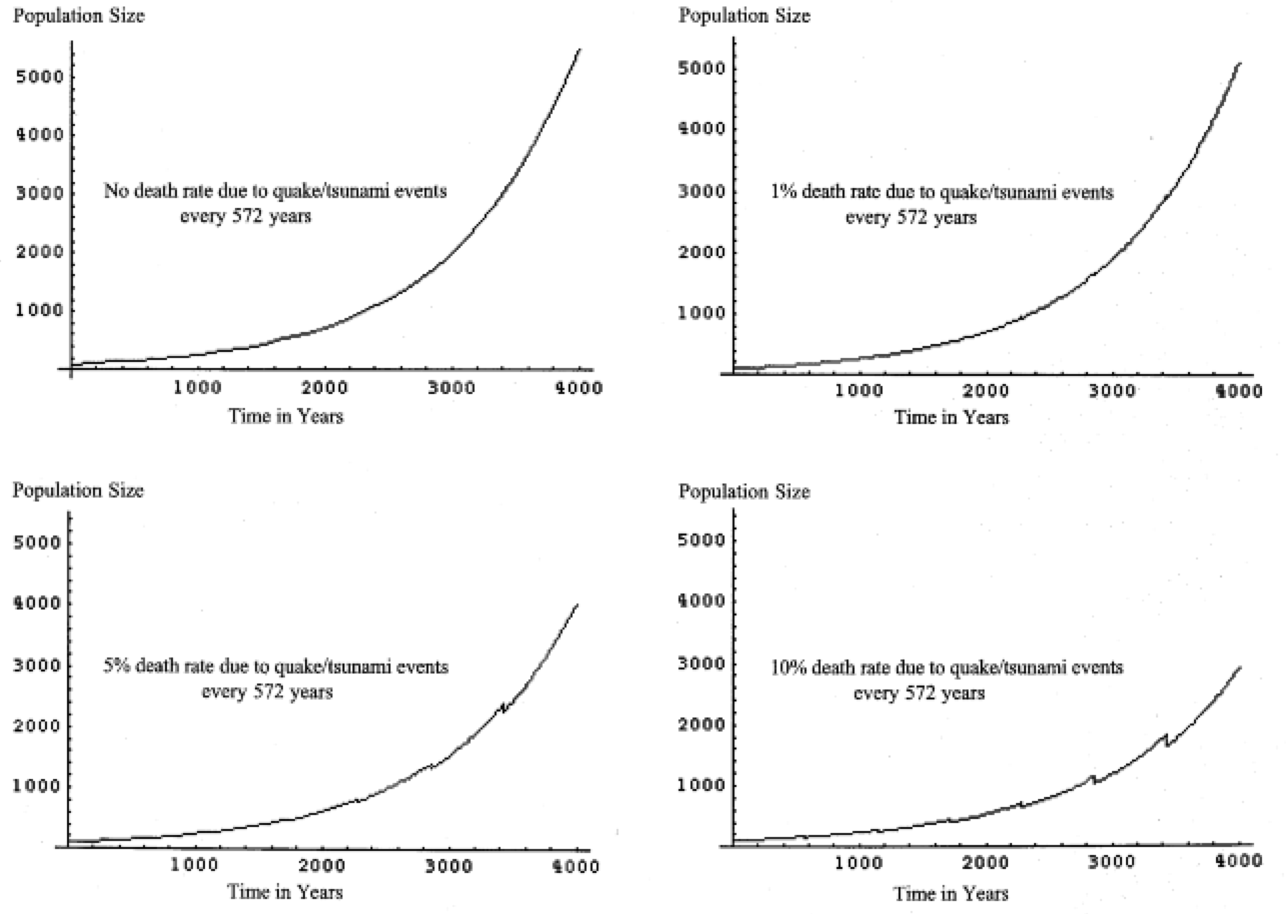


Figure 4. Population models with death rate of zero, 1%, 5%, and 10%.

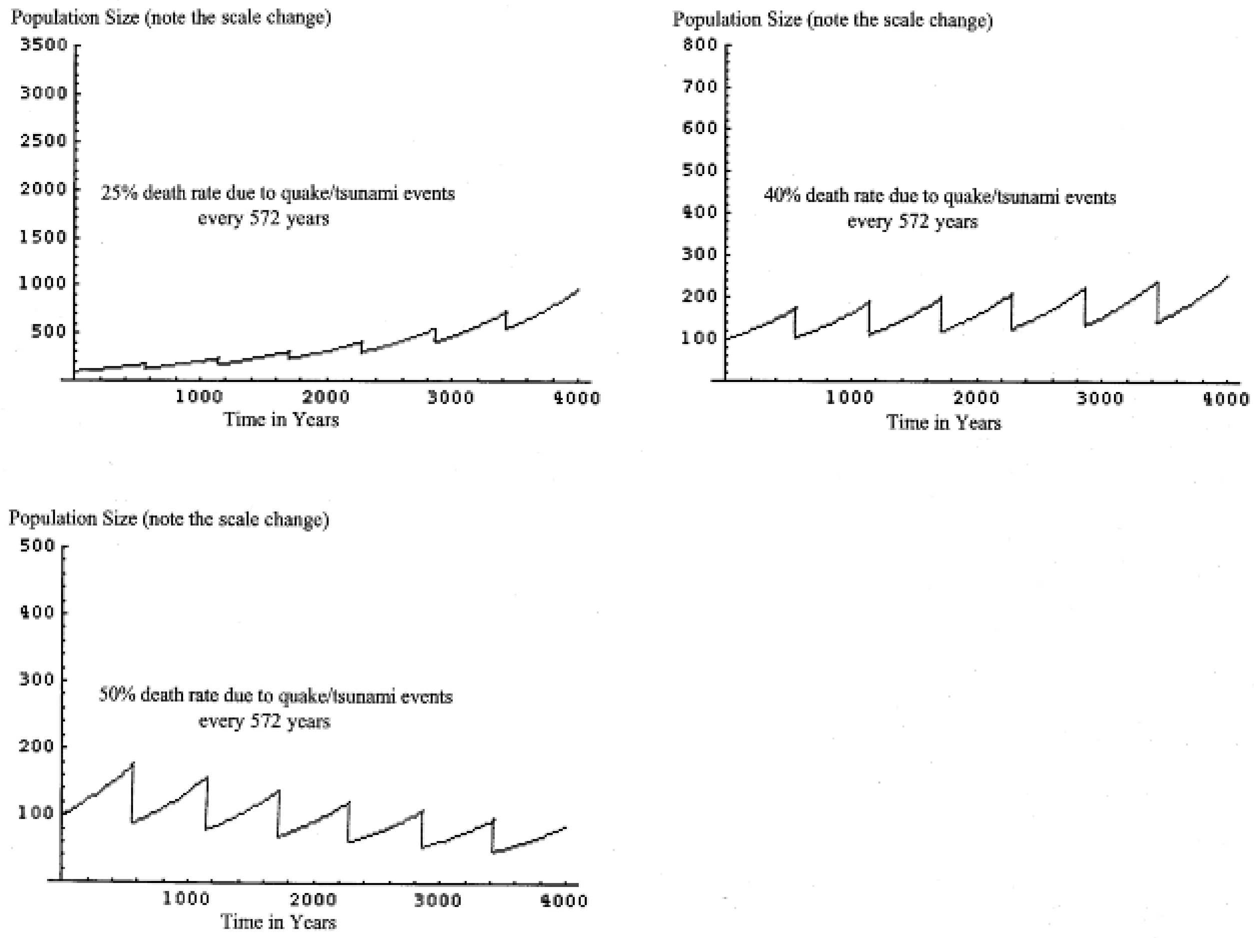


Figure 5. Population models with death rate of 25%, 40%, and 50%.

Could this be used to explain the relatively low populations on the Northern California to southern Washington coast? I think it has some explanatory power, but cannot be tested with our current levels of data. I suspect that great subduction quake events with their tsunamis merit greater attention when trying to understand Oregon coastal prehistory and population demography.

There may be some research questions that can be looked into in relationship to such events. Is there a change in settlement pattern after an event? With enough C^{14} dates, it may be possible to look at site distributions in relation to tsunami run-up lines at 100 year intervals to see if over time, fewer lowland sites are occupied after an event and more lowland sites are occupied as collective memory of specific events fade over time?

Is the concentration in sites in higher rocky habitat simply resource related or is it also quake/tsunami oral history related as well? Looking at patterns of change after events and between events may address such questions. There is no doubt that rocky habitat is more resource productive. But is it also symbolically more safe within traditions where periodic great subduction quakes affect human ecology?

It may be possible to find sites that have been impacted by quake events to see the quality and quantity of the damage. Locating and recording sites buried by drops in land level and mapping in the geophysical parameters of events will also supply data. Estimating impacts to biotic systems and ecologies is also needed as supporting documentation. The impacts to biotic systems of the changes in physical habitat would have required adjustments in local resource exploitation strategies. Looking for such changes in site biota can offer clues to such changes.

In addition, the available prime real estate available for settlement is somewhat restricted along the Oregon coast. The relatively flat areas close to coastal marine resources makes up a small percentage of the land forms in comparison to relatively steep terrain of the coast. While there are flat beaches, sandy beach habitat is relatively sterile in available resources in comparison to the estuary and rocky habitat zones. Analysis of the relative impacts of earthquake damage and tsunami damage for preferred settlement zones is needed. Geophysical changes due to mass events (landslides) in rocky habitat zones may offer clues to impacts to human ecology. Local drops in shallow rocky habitat, changing shellfish abundance is another factor.

As pointed out by Connolly (personal communication 2001), one must factor in the waves of disease that impacted human populations after European contact. I have no doubt that there were major die-offs soon after 1492, and there may have been earlier waves of disease from early Viking exploration. Shipwrecks from the Far East are known from artifacts recovered in the archaeological record. Disease could have been a factor there as well. One must incorporate these factors into the record as well. Part of the low population levels found upon first exploration must be attributed to these causes. Research into the full range of demographic impacts is needed.

There are many possible causes, but the data is suggestive that part of the explanation for the relatively low population levels may be attributed to periodic great subduction events that caused some level of population loss. All living systems are complex and non-linear. The graphs are each based on a constant level of population loss at each event. Reality would have been much more complex. One event may have hit lightly and another with heavy loss of life and property. Another may have been negligible. Impacts probably differed from local area to local area. Events were not regular, but varied between less than 300 to more then 1000 years apart. But the graphs do illustrate the long term potential effects of multiple events that happen over a period of time. They are illustrations of possibilities rather than a model of reality.

Our explanatory power is limited to our models. Models can predict consistent outcomes (internally accurate), but can be absurd. Who cares if the question is wrong as long as the answer is right? Models can generate choice, but simply because there is a choice does not mean that any one of them has to be right. And, we are stuck with the data we have and none of it may be right. Much of it may be misleading or wrong.

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