Discovery of the tallest redwoods in the Santa Cruz Mountains – their distribution and ecology

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Abstract

A search for tall trees in the coast redwood (Sequoia sempervirens) forests of the Santa Cruz Mountains was undertaken in the summer of 2012. Almost all publicly-accessible old-growth stands were searched, leading to the discovery of eleven additional trees greater than 90 m (295.2 ft) tall in several different stands. The tallest tree found was 100.01 m (328.1 ft) tall and was located in Big Basin Redwoods State Park. The previous record holder in the Santa Cruz Mountains was a redwood 93.08 m (305.38 ft) tall found in Portola Redwoods State Park.[1] In this article, we will discuss the ecological value of tall trees and speculate on the environmental conditions that favor the development of the tallest trees.

Introduction

Naturalists and scientists have searched the northern reach of the redwood range in California and found some exceptionally tall trees, including Hyperion, at 115.72 m (379.65 ft) tall, the world's tallest known tree measured by Stephen Sillett in September 2011.[2] However, very little effort has been directed toward the southern part of the redwood range and prior to this study only three trees were known to exist that were more than 90 m tall.[3]

The coast redwood is a fast-growing, massive, and long-lived tree species that grows taller than any other tree in the world.[4] Its natural occurrence is restricted to the coastal belt of summer fog or low stratus cloud cover that ranges from southwest Oregon to central coastal California and is only 8 – 58 km (5 – 35 mi) wide.[4] Redwoods reach their best development in northern California where rainfall amounts and the frequency of summer fog are greater than in the Santa Cruz Mountains which are located in the southern portion of the redwood range.[5,6,7]

Redwood forests, especially the few remaining old-growth stands, play a strong role in shaping their ecosystems. Individual trees can have an inordinately large impact on their forest stands. Below we discuss the impact of these trees in affecting water capture and providing living space for canopy flora and fauna, especially the endangered marbled murrelet (*Brachyramphus marmoratus*).

One way that redwoods capture water is through fog drip. Fog drip is moisture stripped from fog by vegetation, especially needle-leaf trees, which coalesces and drips onto the ground below. On the west coast of North America, it occurs primarily during the summer season when advection fog forms offshore and is pushed inland and upward against the coastal range by prevailing westerly winds.[8] Work done by Dawson of U.C. Berkeley in a northern California site that received heavy amounts of fog drip, found that up to 45% of the water used by redwood trees originated as fog drip precipitation.[9] Fog drip onto the soil underneath a tree can not only increase plant available water but can also, over the long term improve biotic and abiotic soil properties.[10,11] Recent studies have shown that redwood leaves can absorb some water directly from fog.[10]

Several studies have shown that fog drip is maximized under individual forest trees that are located in an exposed position such as on the windward edge of a stand or are taller in height than the rest of the stand.[9,11,12,13] Oberlander measured fog drip with a single collector gauge under each of five trees for a five-week period between July and August on Cahill Ridge in the Santa Cruz Mountains.[13] He collected 45 mm of fog drip precipitation under a mature redwood in the interior of a forest on the lee side of a ridge, while a Douglas-fir tree in a fully exposed position on the ridge top received 434 mm of fog drip.

Old-growth redwoods and Douglas-firs develop large branches that provide a substrate for other life forms. A diverse community of lichens, mosses, ferns, insects, arthropods and other species is sometimes found in the canopies of old-growth trees. These epiphyte communities are slow to form and only exist because long-lived trees are present in a stable environment that allows them to grow very old. In Northern California, where the climate is wetter and crown fires are less frequent, these epiphytic communities have reached their greatest development – even supporting a new population of totally arboreal salamanders.[14,15] In the Santa Cruz Mountains epiphytic communities have significantly less vegetation cover and a more limited biodiversity, but they still provide habitat for an endangered bird species – the marbled murrelet.[16]

The tallest trees in a stand may provide preferred nesting sites for the marbled murrelet. A study of 59 murrelet nests in British Columbia found that trees selected for nesting were both taller and larger in diameter than other trees in the stand.[17] A study of all documented nests in the Santa Cruz Mountains did not find a preference for taller trees, but the sample size was only 17. However, that study did find a statistically significant preference for murrelets to nest in the largest diameter trees in a stand.[18] A study of nine nests in Redwood National Park did not find that murrelets selected taller trees when choosing a nest site, but did find that the average tree height of successful nests (58.6 m) was taller than the average tree height of failed nests (52.8 m).[19] In both cases the average nest height was similar. We postulate that murrelets may prefer taller trees and/or larger trees because they have higher quality potential nest sites.[17,18]

Knowing the habitat variables that are most favorable for redwood growth in the Santa Cruz Mountains will be helpful when trying to understand how changes to these parameters brought about by global warming will impact tree growth. Extensive information is being collected at a different old-growth tree stand in Big Basin Redwoods State Park through the Redwoods and Climate Change Initiative Study instigated by the Save the Redwoods League, but no studies have yet looked at the habitat variables held in common by all known tall tree areas. Through this simple study we hope to initiate that exploration.

Study Area

The study area consisted of almost all the publicly-accessible old-growth redwood stands in the Santa Cruz Mountains which included 12 properties ranging in size from 8 to 1,845 ha (20 to 4,560 acres) in size (see Table 1) and totaled 2,880 ha (7,116 acres). Stands searched for tall trees included Big Basin, Portola, Henry Cowell, and Butano state parks, and several county parks (see Table 1 and Figure 1). The areas that were surveyed represent about 70 percent of the remaining old-growth in the Santa Cruz Mountains.[20] These include most of the alluvial flat or valley bottom stands, which are known to support the largest trees.[21] Consequently, we believe there will be few if any exceptionally tall trees in the old-growth stands that we did not examine.

Methods

We used maps of old-growth stands that we had produced previously to prescribe the areas that would be searched for exceptionally tall trees.[20,22] These maps covered the entire Santa Cruz Mountains and were based on stereoscopic review of black and white aerial photos produced for the Big Creek Lumber Company in 1994 at a scale of 1:15,840. Old-growth stands were defined as stands having at least 10 old-growth trees per acre with old-growth trees being characterized by having old-growth structure (such as old-growth crown and branch structure) and having a diameter at breast height (DBH) of at least 1.0 m (3.28 feet). Old-growth trees were identified based on a combination of factors, including crown shape, size, gray-scale color, and the relative height of dominant trees compared to other trees in the stand. The advantage of stereo imagery is that it provides the dimension of height which allows one to recognize the tight clusters of second-growth redwood that originate from stump sprouts and appear to be a single large-crowned old-growth tree when viewed on regular two-dimensional aerial photos, orthophotos, or computer-generated aerial photos.

We searched for tall trees by walking through old-growth stands, bordering slopes, or ridgetops and looking into the stand. A majority of the trees in each surveyed stand were measured with a hand-held Impulse 200 LR Laser Rangefinder, which had an accuracy of plus or minus 0.30 m when hand-held and plus or minus 0.05 m when mounted on a tripod.

The height of all potential trees greater than 90 m was measured by trigonometric leveling using a tripod-mounted Impulse 200 Laser Rangefinder and a tripod-mounted prism. The top of the tree was defined by sighting on the characteristic top tuft; the bottom of the tree was at the ground level. The ground level was taken to be the average of the top of the litter layer on the uphill side of the tree and the top of the litter layer on the downhill side of the tree.

The DBH of each tree was calculated from the circumference at 1.37 m above the lower ground level of the tree. If the tree was located on a slope and the upper ground level was more than 1.37 m above the lower ground level, then the circumference was measured at the upper ground level.

Although we discuss them below, we did not measure other ecological attributes of tall trees such as the number of potential murrelet nest sites or the quantity of fog drip. We estimated fog drip for our exceptionally tall trees by relying on a previous review of fog drip potential in the Santa Cruz Mountains.[23]

Results and Discussion

Ten trees taller than 90 m (295.29 ft) were discovered and one more was found with a height of 89.93 m (295.05 ft). We consider these to be exceptional trees as previously there were only three trees known to be 90 m or taller[1,24,25]. These exceptionally tall trees were in solitary settings, except for one small grove of four trees, and were found only in Big Basin Redwoods State Park and Portola Redwoods State Park (see Table 2). Some trees almost as tall were found in Heritage Grove County Park. The DBH values ranged from 2.59 m (8.5 ft) to 4.45 m (14.6 ft), although several trees had fused multiple trunks at breast height and were not measured.

For a tree to become one of the tallest trees in the stand, it needs a combination of good longevity and optimal growing conditions. Growing sites with reduced incidences of wildfire, high winds, and falling trees (especially comparatively short-lived Douglas-fir trees) might provide the longevity, but the environmental conditions that optimize growth rates in old-growth redwoods are not fully known – especially in the redwood's southern range.

We looked at six of the most basic physical environmental parameters associated with these exceptionally tall trees and present the results in Table 3 below.

Our initial review of the site conditions associated with these 14 tall trees suggests that the following habitat variables warrant additional investigation (Table 3): (1) perennial water source present, (2) average annual precipitation of at least 1070 mm (42 in), (3) moderate to high frequency of stratus cloud cover, (4) alluvial or lower slope landscape position, (5) location between 10.8 and 12.1 km from the coast, (6) location within a deep canyon setting, and (7) location on a site free from historic crown fires.

Perennial water source

13 of 14 tall trees had a perennial source of either surface or near-surface water, whether it was a spring, creek, or both. For the coast redwood and other tree species as well, perennial water promotes maximum growth because it allows for maximum water intake–something vital for tree height.

Old-Growth Stand Number	Old-Growth Stand Name	Stand Size (ha)
1	Big Basin Redwoods State Park	1,845
2	Portola Redwoods State Park	391
3	Butano Redwoods State Park	243
4	Pescadero Creek County Park	130
5	Memorial County Park	97
6	Henry Cowell State Park	65
7	Roaring Camp Railroads	51
8	Nisene Marks State Park	15
9	Miller Property County Park	13
10	Heritage Grove County Park	12
11	Sam McDonald County Park	10
12	San Francisco YMCA Camp	8
	Total	**2,880 ha.**

Table 1. Old-growth Stands Searched
Note: Old growth properties searched were given a number based on amount of area. These properties' numbers are found on the corresponding map (Figure 1).

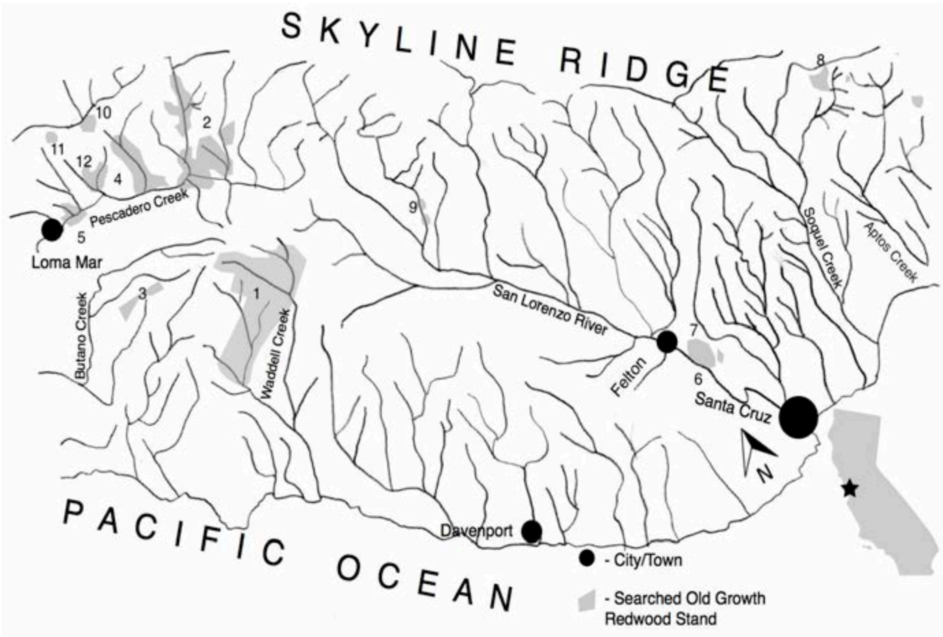

Figure 1. Location of Old-Growth Stands that were Searched for Exceptionally Tall Trees
Note: This map displays the areas searched by the authors (in grey). Stand numbers refer to the stand names found in Table 1.

Precipitation more than 1070 millimeters (42 inches)

All 14 of the tall tree sites had average annual precipitation of 1070 mm or more. Rainfall within the redwood region of the Santa Cruz Mountains varies from 741 to 1236 mm, with the higher amounts associated with higher elevations.

Moderate to high frequency of stratus cloud cover

A stratus cloud or fog layer is frequently associated with the redwood belt in summer months.[8] Its presence benefits redwood water relations through higher humidity levels and cooler temperatures that act together to reduce the evapotranspiration rate. The top of the summer stratus cloud layer on the coastal side of the Santa Cruz Mountains is typically between 455 and 610 m high, although it varies from day to day.[27] Redwoods are not confined to locations below 610 m and our search for exceptionally tall trees was not limited to areas below 610 m in elevation. Since the stratus layer penetrates inland from the ocean, trees growing on locations less than 455 m elevation and not blocked from the ocean by an intervening north-south ridge would frequently be under the stratus layer. In contrast, trees growing at elevations above 610 m, or at other elevations on the leeward side of ridges that were 610 m or higher, would seldom be under the stratus layer. Using these considerations, we estimated the frequency of stratus cover for our tall trees in Table 3 as "high" or "low", respectively, with situations in-between rated as "moderate". All but one of the tall tree sites rated moderate and the other rated high.

Alluvial or lower slope position

13 of 14 tall trees were located on either an alluvial plain or a lower slope topographic position and one tree was located on a stream terrace. Alluvial sites and lower slopes are usually associated with higher soil water availability.

Location between 10.8 and 12.1 km from the coast

Of the fourteen redwood tall trees known, nine are positioned from 10.8 – 12.1 kilometers (6.7 – 7.5 miles) away from the coast. Why this is the case remains unknown. A similar condition exists in northern California (Mendocino, Humboldt, and Del Norte counties) where the tallest coast redwoods are found from 8.0 – 11.2 km (5.0 – 7.0 miles) from the coast.[1] In our study, the closest redwood over 90 meters was located 8.4 km (5.2 miles) from the coast and the furthest redwood over 90 meters was located 18.5 km (11.5 miles) away from the coast (see Figure 2). In the northern redwood range, the closest redwood known over 106 meters (350 feet) is approximately 4.6 kilometers (2.85 miles) away from the coast and the farthest redwood known over 106 m is 45 kilometers (28 miles) away from the coast.[1]

Deep canyon settings

Ten of our exceptionally tall trees were growing in deep canyon settings. These were locations where a ridge at least 75 m higher than the base of the tree was within 300 m or less of the tree and located to the south or west. Trees growing under such conditions would benefit from lower evapotranspiration rates due to such factors as shading in the late part of the day, cooler temperatures, protection from drying winds or wind damage, and increased local humidity. These conditions could favor more rapid tree growth if soil moisture was a primary limiting factor and irradiation levels were sufficient.

Trees regularly compete with neighboring trees for sunlight until one tree grows higher than its neighbors. However, trees growing in a deep canyon may still be shaded for part of the day or shaded in part for all the day. In canyons with a bordering ridge on the south or west, we observed that shading from the ridge blocks direct sunlight for an extra half-hour or hour before sunset each day. Yet if a tree is appropriately located, it can grow tall enough to extend into the direct sunlight above the ridge's shadow. We speculate that some of our tall trees grew as tall as they did because they were competing with a bordering ridge for sunlight. This is analogous to the situation of seedlings grown in solid-walled translucent tree shelters that provide some degree of lateral shading. Such seedlings, including redwood seedlings, will grow taller faster than open-grown unshaded trees in order to extend above the top of the tube where direct sunlight is available.[28,29,30] Thus deep canyon settings may encourage the development of exceptionally tall trees.

Sites free from severe crown fires

The mean fire recurrence interval in redwood forests of the Santa Cruz Mountains has changed over time. Prior to the 19th century, and under the influence of aboriginal burning, it was reported to be between 8 and 12 years (for northeastern Santa Cruz Mountains) and 17 and 82 years (for southern Santa Cruz Mountains).[31,32] In the 1800's and early 1900's fires were more frequent due to logging activities and the recurrence intervals were reported to be either 4 to 12 years or 20 to 50 years.[31,32] Since then fires have been much less frequent.

In all cases, the majority of the fires were ground fires that did not spread into the crown, or only did so in an occasional tree or group of trees. Widespread crown fires, where the fire spreads directly from crown to crown, were very uncommon.[33] Historical records indicate that the last severe crown fire to impact a large part of Big Basin Redwoods State Park was the 1904 fire which started near Waterman Gap and

Old-Growth Property	Height of Tallest Tree (m)	Number of Exceptionally Tall Trees
Big Basin Redwoods State Park – East Half	100.01 (328.12 ft)	9
Big Basin Redwoods State Park – West Half	92.20 (302.48 ft)	1
Portola Redwoods State Park – North	91.97 (301.75 ft)	2
Portola Redwoods State Park – South	93.08 (305.38 ft)	2
Heritage Grove County Park	88.81 (291.39 ft)	0

Table 2. Distribution of Exceptionally Tall Trees by Location. This table shows the distribution of tall trees (>90 m) in the tallest Santa Cruz Mountain groves.

Trees as identified by height (m)[1]	Extant Perennial Water Source?	Approx. Annual Ppt.[2] (mm/yr)	Rel. Freq. of Summer Stratus Cloud Cover[3]	Landscape Position and Aspect	Elev. (± 15 m)	Distance from Coast (km)
100.01[4] (328.12 ft)	Yes, Spring	1190	Mod.	Lower Slope SW	435	11.3
99.17[4] (325.36 ft.)	Yes, Spring	1190	Mod.	Lower Slope SW	435	11.3
93.08* (305.38 ft)	No	1120	Mod.	Lower Slope S	225	16.6
93.02 (305.18 ft)	Yes, Spring, Creek	1170	Mod.	Alluvial Site	225	18.0
92.95 (304.96 ft)	Yes, Spring	1190	Mod.	Lower Slope NE	435	11.3
92.23 (302.58 ft)	Yes, Spring	1220	Mod.	Lower Slope E	330	11.6
92.20 (302.48 ft)	Yes, Spring	1120	High	Alluvial Site	180	8.4
91.97 (301.75 ft)	Yes, Creek	1070	Mod.	Alluvial Site	210	18.5
90.33 (296.39 ft)	Yes, Creek	1220	Mod.	Lower Slope N	375	10.8
90.29 (296.22 ft.)	Yes, Creek	1120	Mod.	Lower Slope NE	195	18.3
90.22*[5] (296.0 ft.)	Yes, Creek	1220	Mod.	Alluvial Site	315	11.6
90.13* (295.70 ft.)	Yes, Spring	1220	Mod.	Terrace	330	10.8
90.11 (295.63 ft.)	Yes, Spring, Creek	1190	Mod.	Lower Slope NE	390	12.1
89.93 (295.05 ft.)	Yes, Spring	1190	Mod.	Lower Slope NE	435	11.3

Table 3. Environmental Conditions Associated with Exceptionally Tall Trees

[1]Asterisks (*) indicate trees known previously and not discovered by us.
[2]Rantz, 1971.[26]
[3]Estimated relative frequency of stratus cloud cover, rated as High, Moderate, or Low and based on elevation, topographic position, and distance inland.
[4]Height measured by Steve Sillett in September 2012 via direct tape drop.[2]
[5]Height measured by Steve Sillett in December 2009 via direct tape drop.[2]

Figure 3. Top of Old Tree in Portola Redwoods State Park

Figure 4. Typical Tall Tree Top

Figure 5. Spire-shaped Tree Top

spread rapidly under the influence of strong and dry northeast winds through the eastern portion of the park.[34] Park fire history maps and historic maps, indicate that the area containing the greatest collection of tall trees in Big Basin was not impacted by the 1904 fire and only two of our tall trees were found within the 1904 burn area.[35,36] This may reflect the fact that crown fires, even though they seldom kill redwoods, will kill the tops of the trees where the bark is thinner and there is less protection for dormant buds. Height growth will be delayed because a new leader will have to form at a lower point on the tree bole. Moist canyons, like streamside groves, might have a lower probability of experiencing crown fires, which would reduce the risk of top damage and also increase the longevity of trees growing there, potentially allowing them to reach higher heights.[33]

Surface fires may also influence tree growth rate through the formation of fire scars including large basal hollows in live trees called goosepens. We observed that none of our tall trees had goosepens even though nearby trees occasionally did. We postulate that the effects of goosepen formation, such as the loss of the basal sapwood (including the xylem layer which conducts water upwards in the tree) and loss of the associated root network (due to loss of the phloem layer) are significant factors that can reduce tree height.

Other observations

All of the tall tree redwoods south of San Francisco have live tops. Thirteen of the trees have an erect, straight top leader. Old Tree in Portola Redwoods State Park happens to be the exception. Currently, Old Tree's leader is leaning rather distinctly but tree height is still 93.08 meters, indicating a significant growth in height since its last measurement in 2007 (see Figure 3).

All but one of the straight-topped trees resemble Figure 4, a 91.97 m tree found in Portola Redwoods State Park. The crown has many lateral branches near the top of the tree with a vertical leader exactly in the middle of the tree. Another tree in Portola Redwoods State Park has a very small top without many lateral branches near the top (see Figure 5). Its first large branch is 20 feet below the top. Many young redwoods have crowns similar to this. Young trees emphasize growth in height initially and then once they've reached maturity, they branch out more and grow much more slowly in height.[37] This tree's small, pointed top and scarcity of lateral branches below suggests that it will keep growing and gain height more quickly than the other 90 m trees in Table 3.

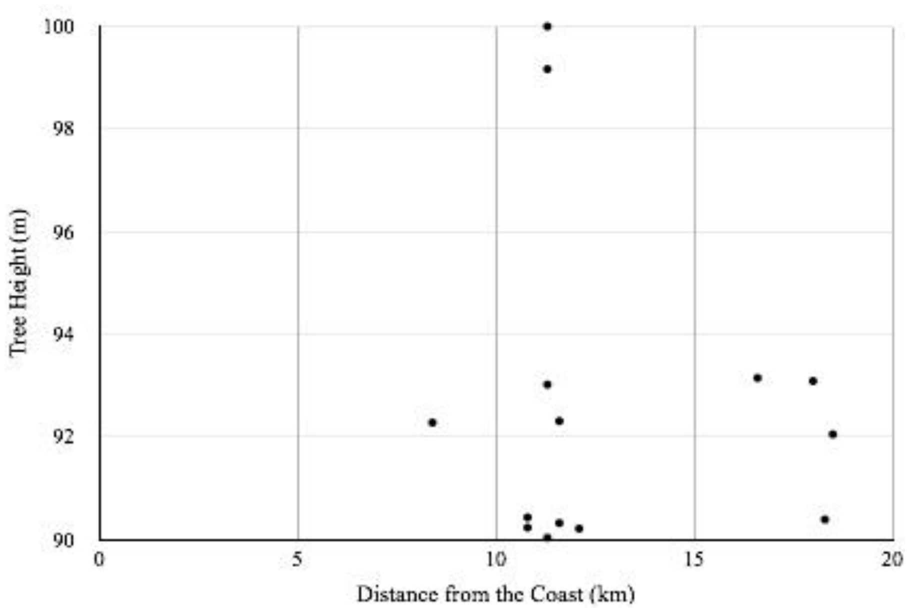

Figure 2. Exceptionally Tall Trees and Their Distance from the Coast

Conclusions

Although redwoods in Santa Cruz Mountains do not grow as tall as do redwoods in Northern California, they can grow as high as 100.01 m (328.12 ft), which is higher than they are known to achieve in Marin County to the North and Monterey County to the South.

Exceptionally tall redwoods in the Santa Cruz Mountains are most closely prescribed by the presence of a perennial source of water, either spring or stream, and being situated inland from the coast at least 8.4 km and usually 10.8 km or more yet still lying within the marine overcast zone. A majority of the 90 m trees stand in the bottom of a deep canyon. Such settings can reduce evapotranspiration through shading in the late parts of the day, cooler temperatures, and increased humidity, thereby favoring more rapid tree growth. Although global warming models for Central California are unclear as to the changes that will occur in fog frequency and annual precipitation, other evidence has found a decrease in fog frequency.[38,39,40] It is clear that average annual temperatures will increase, and therefore refuges provided by streams, spring-side areas, deep-canyon settings, and other as yet unidentified habitat variables (such as soil conditions) may be vital for the maintenance of healthy redwood communities.[39] Through further investigation of our tall tree areas we hope to identify what other factors may be important for producing exceptional redwood trees in the Santa Cruz Mountains.

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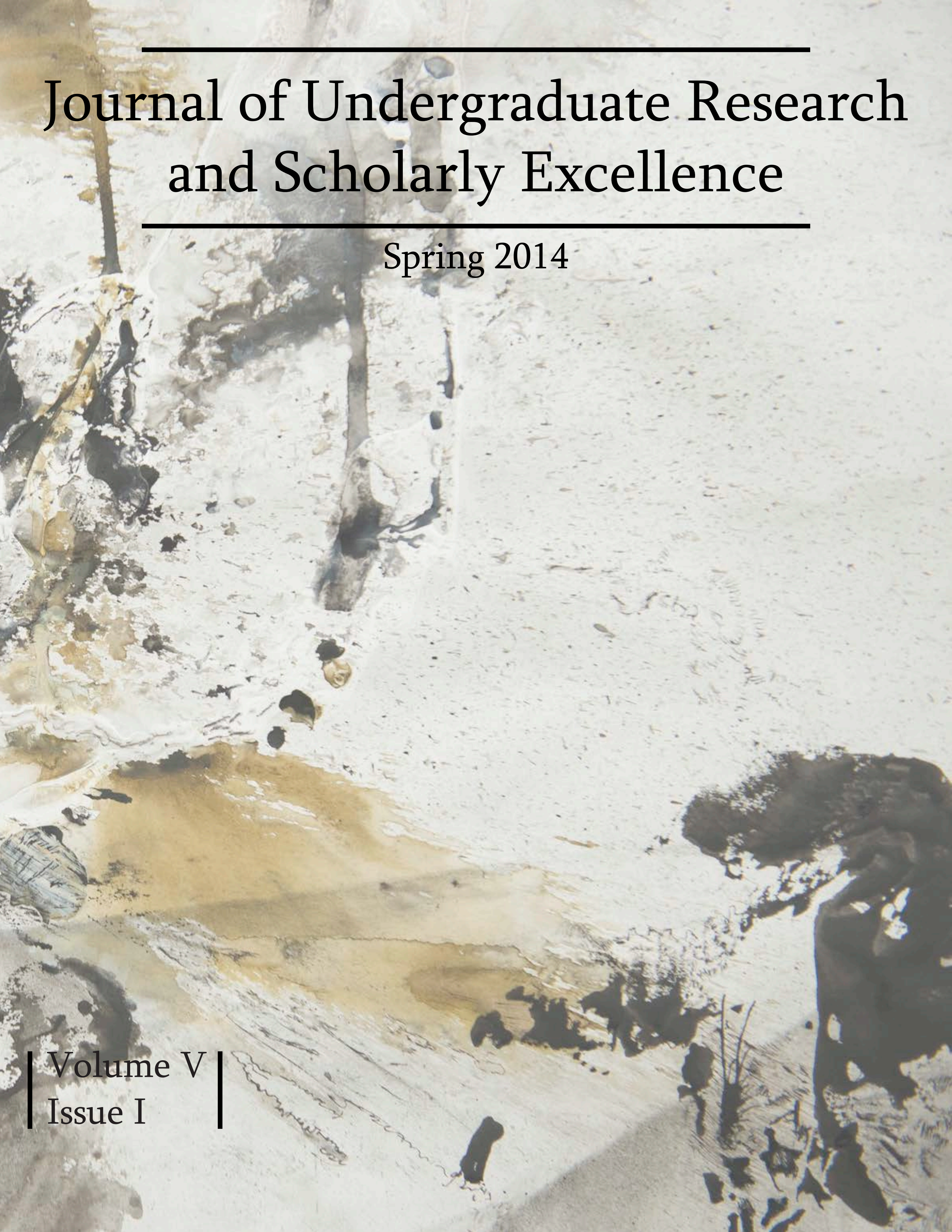

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Issue I