Tomales Bay State Park Forest Inventory

Produced for California State Parks

by

Avocet Research Associates

and

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Acknowledgments

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Abstract

A 2019 forest inventory at Tomales Bay State Park included 50 sample plots of the forested areas within the 962-acre northern block of the park. Analyses of the resulting data indicated high levels of tree disease and mortality in declining populations of bishop pine, tan oak and coast live oak. The inventory also demonstrated that, absent some natural or human intervention, there is insufficient natural regeneration to sustain the bishop pine and tan oak forest. Instead, much of the park is covered with standing dead and fallen trees, woody debris, a dense impenetrable understory of native shrubs, and deep organic ground layers of litter and duff which inhibit forest regeneration and contribute to heavy surface and ladder forest fuel loads.

Introduction

Tomales Bay State Park is a 2434-acre unit of the California State Parks system with 3.5 miles of sheltered coastline on Tomales Bay. The park was used by 38378 registered day users in 2017[1] for hiking, swimming, picnicking, boating, education and other coastal recreational activities. Many more used free access points. Elevation ranges from sea level to 550 feet. The northern California coastal climate rainfall averages about 35 inches per year, but annual fluctuations ranged from less than 20 inches to over 60 inches during the past decade. The northeast-facing hillsides descend to the shoreline along forested ridges and canyons of moderate slope vegetated with dense native bishop pine and mixed hardwood forest with associated understory vegetation. This forest is part of a complex of vegetation types on both sides of Inverness Ridge which includes 3570 acres of closed-cone bishop pine forest (US-NPS 1994). This species has very restricted native range and has been cited on by the IUCN as a “vulnerable” species (Fargon 2013). In addition to bishop pine forest, the moist slopes and ravines draining the decomposed granitic hillsides are interspersed with wetlands, open pastoral lands, and shrublands. Although this native forest provides the backdrop to the many recreational activities at Tomales Bay State Park, the forest has few access routes and only three trails, the Johnstone Trail, Jepsen Trail and Indian Beach Trail. The forest itself is largely inaccessible as dense understory thickets discourage even foot travel throughout most of the park.

There is broad concern regionally regarding forest health, and the bishop pine forest is no exception. It is clear to even a casual observer that the bishop pine forests, which extend up and down the California coast, have in recent years been in a state of steady decline with high numbers of live diseased, standing dead and fallen dead trees throughout and beyond the park. Tree and forest mortality is the manifestation of ecological conditions that are associated with lack of fire, indigenous and introduced tree pests and diseases, including a variety of bark beetles, pine gall rusts (*Peridermium cerebroides and P. harknessii*), pitch canker (*Fusarium circinatum*) and Sudden Oak Death (*Phytopthora ramorum*), an aging tree population, and the recent five-year drought. The regular heavy

[1] July 2016 through June 2017. Email from ‘Planning@parks.ca.gov’ October 19, 2019

leaf fall and accumulation of woody debris have resulted in litter and duff layers of extraordinary depth (up to 10 inches or more in many Tomales Bay State Park locations). The fragmented forest canopy, the abundant live and dead woody organic ground cover, and the dense canopy of sprouting coastal shrub species have essentially inhibited natural native forest regeneration for many years.

As bishop pine is not a late-successional species it is therefore normal to think that long-lived hardwoods such as coast live oak (*Quercus agrifolia*), tanbark oak (*Lithocarpus densiflorus*) and California bay (*Umbellularia californica*) would account for an ever-increasing proportion of the forest biomass, and that is what is happening at Tomales Bay State Park. Native Americans evidently burned the landscape, which may have resulted in successive even-aged forests of bishop pine. A research team from University of Hawaii reported that pollen analyses from sediment cores in Tomales Bay demonstrated that bishop pine has occurred on the Inverness ridge for 6000 years or more (Smith et al. 1989). Without occasional fire, the coastal bishop pine forests cannot thrive. Bishop pine is a fire-friendly closed-cone species with a relatively short life span. The species normally regenerates from seeds that fall onto the freshly exposed bare mineral soil when the serotinous cones open following fire. Fire history maps of the area show that one of the last fires in the area was the Shafter Ranch Fire "stopped at Shell Beach" in September 1932[2]. Aerial photos from the 1940's and 50's show young forests, open areas, and overall less biomass in the landscape, and those are the mature and dying trees that we see there today.

Methods

In view of the discussion above, natural resource staff of California State Parks contracted with Avocet Research Associates to develop a forest inventory for Tomales Bay State Park's main 962-acre block. This effort is a baseline onsite resource analysis that can serve as the foundation for consideration of forest management alternatives. Avocet Research Associates proposed that 50 sample plots be installed at random locations at the Park. Each plot included a 20-BAF (basal area factor) variable radius plot for live and dead trees 2.5" and larger, a 1/100th acre plot for live tree seedlings and saplings (<2.5" diameter at breast height (DBH)), an estimate of vegetation cover association, percent grass cover, percent shrub cover, fuels transects and a count of down logs 8" and larger in diameter on a 1/24th acre fixed plot. Each plot also includes photos in the four cardinal directions and a ground cover photo. In addition to the inventory, approximately 17 trees were selected for tree ring counts. Because of the impenetrable nature of this forest, some random alternate plots were also selected in the event that primary plots were inaccessible. Tom Gaman, Registered Professional Forester, developed the specifications, did the field work and wrote this report. For precise details of specifications for the forest inventory, see the appendices.

The random plot locations were compiled into a GIS shape file and the plot coordinates were uploaded to a Garmin 60 GPS. The plots were located on a map and 50 plots were visited in the field. The data were entered into a handheld field data recorder using a data

[2] https://www.marinfirehistory.org/1932-shafter-ranch-fire-west-marin.html

entry program that prompted for all inventory items at each plot location, including plot-level and tree-level field notes. The resulting data files were aggregated and uploaded to the FORSEE forest modeling software. FORSEE provides a structured Microsoft Access database for archiving the inventory, computes live tree inventory summaries with growth projections, and includes other analytical tools, e.g. keeping track of sequestered forest carbon and allowing for periodic updates. As such, the data provided in this forest inventory is stored in a FORSEE database and the FORSEE output was used to create some of the histograms and graphics in this report.

Vegetation Types Associations

California Native Plant Society, California Department of Fish and Wildlife and ESRI[3] have recently collaborated to create a digital map of vegetation associations on the public lands in West Marin. I obtained the GIS data set and isolated the Tomales Bay State Park main 962-acre block. The park's vegetation was characterized by the ESRI team as shown in Figure 1.

Tomales Bay State Park Vegetation	
Vegetation Type	**Total Acres**
Bishop Pine	635.0
California Bay	6.9
Coast Live Oak	163.6
Red Alder	22.8
Blue Blossom	12.1
California Annual grassland	9.8
Coyote Brush	80.6
Other	28.1
Built-up	2.8
TOTAL	961.6

Figure 1. Vegetation Type acreages for 962 acres northern block of Tomales Bay State Park from ESRI's CNPS/CDFW Calif Vegetation Map 2018

While this stratification by vegetation type is helpful and will be useful for detailed planning, this inventory focuses on forests and is limited to 50 plots. Plots were not visited in non-forest areas. Non-forested wetland areas were deliberately avoided. Because of the small number of plots the inventory as presented here is "unstratified", which is to say that the summaries are averages that represent the park's forest as a whole and they do not specifically represent individual vegetation type associations noted in Figures 1 & 3. All conifers inventoried on all 50 plots were bishop pine with the exception of a single 53" DBH Douglas-fir, which also happened to be the largest tree (and certainly the oldest conifer) in the inventory.

[3] http://ecp.maps.arcgis.com/apps/webappviewer/index.html?id=09c5e1e62c5e499fa31ee443ad77b944

Forest Age

During fieldwork, 17 trees were randomly selected that were suitable for counting growth rings. These trees were also measured for height. Trees varied in age from 43 to 95 years old. The bulk of the trees measured were between 50 and 75 years of age. Aside from widely-scattered bishop pine regeneration in disturbed areas where bare mineral soils have been exposed there are essentially no younger trees. Bishop pine is generally a short-lived species and, although some trees grow very large on good sites, the older trees on the poorer sites seem to become vulnerable to mortality from drought stress causing attacks by bark beetles (western pine beetle), and increased vulnerability to pine gall rust, and pitch canker. As a result, these trees do not survive much beyond a maximum of 100 years, and the expected life span is even shorter on thin soils. Stands, as discussed in the introduction, are normally renewed by infrequent fire at intervals from 25 to 100 years. Such fires also result in residual pine mortality.

Aerial photos from the 1940's, 50's and 60's show that the forest stocking at those times was generally less extensive. All trees, hardwoods and conifers alike, were smaller (and younger) than those present on site today. Some of the stands that exist today were open pasture and scrublands that were probably grazed. Such observations are consistent with regional trends of less fire, less forest harvest and less active rural land use. Taken together, they have resulted in older forests with larger trees and greater forest biomass.

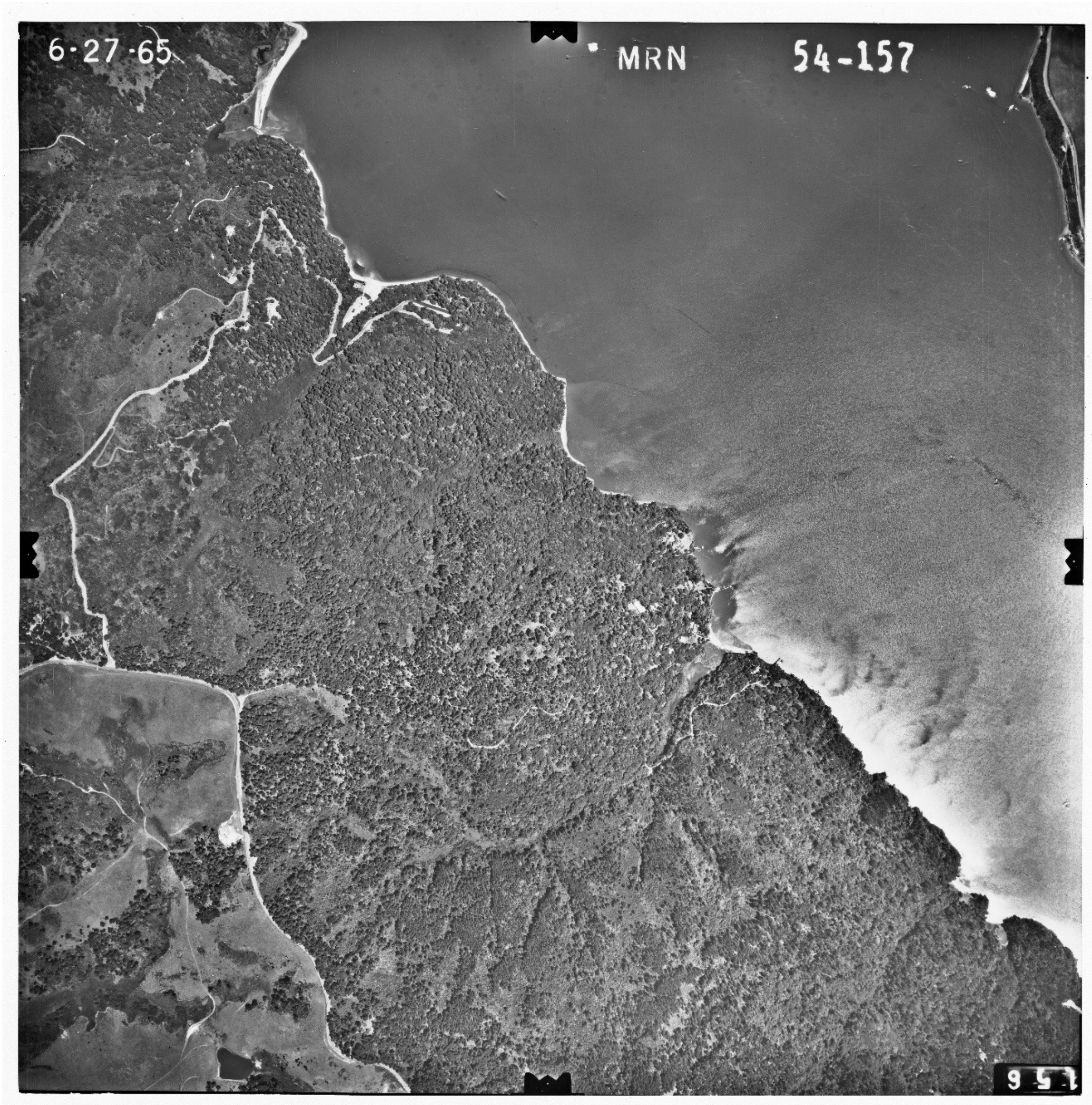

Figure 2. This 1965 aerial photo shows a much younger bishop pine (darker canopies) than exists today. Actually, a large proportion of trees at Tomales Bay State Park were seedlings and saplings when the photo was obtained. Indian Beach is visible at the top left and Shell 1 and Shell 2 are at lower right. Source: Dewey Livingston

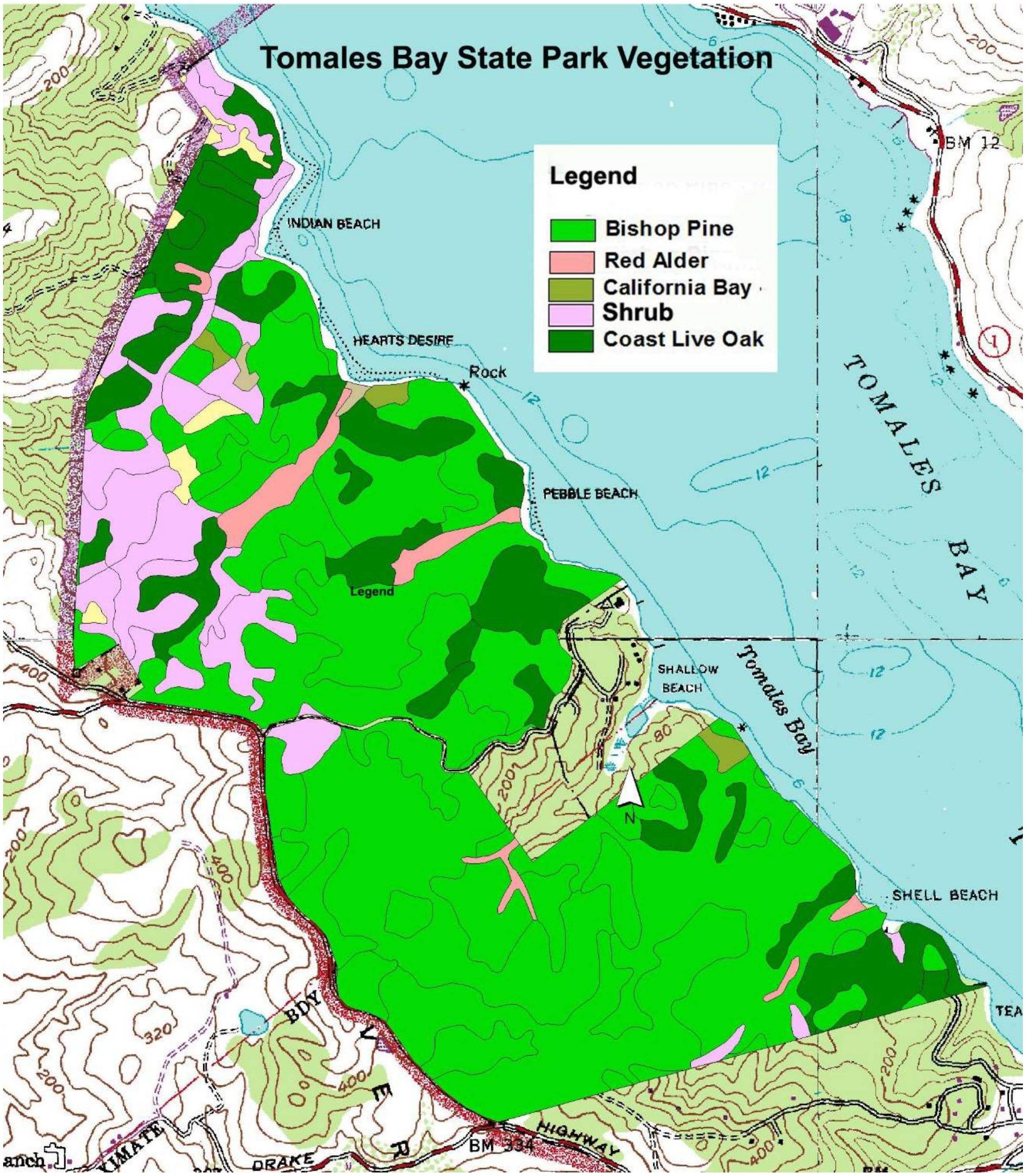

Figure 3. Vegetation Types, Source ESRI's CNPS/CDFW Calif Vegetation Map 2018

FORSEE Live Tree Inventory

The variable radius basal area factor (BAF) inventory sampling method originates from a center point and the chance of a tree being included in the plot is directly proportional to its diameter at breast height (DBH). This survey method is equally suited to measurement of forests of large trees and smaller trees and is good at characterizing forest stand composition. Using a BAF 20 prism (essentially an angle gauge) for the sample means that each tree accounts for 20 square feet per acre of trunk area per acre. As an example a 12" tree within the sample accounts for 20/(/ ((12/24)^2* 3.14159) or 25.46 trees per acre.

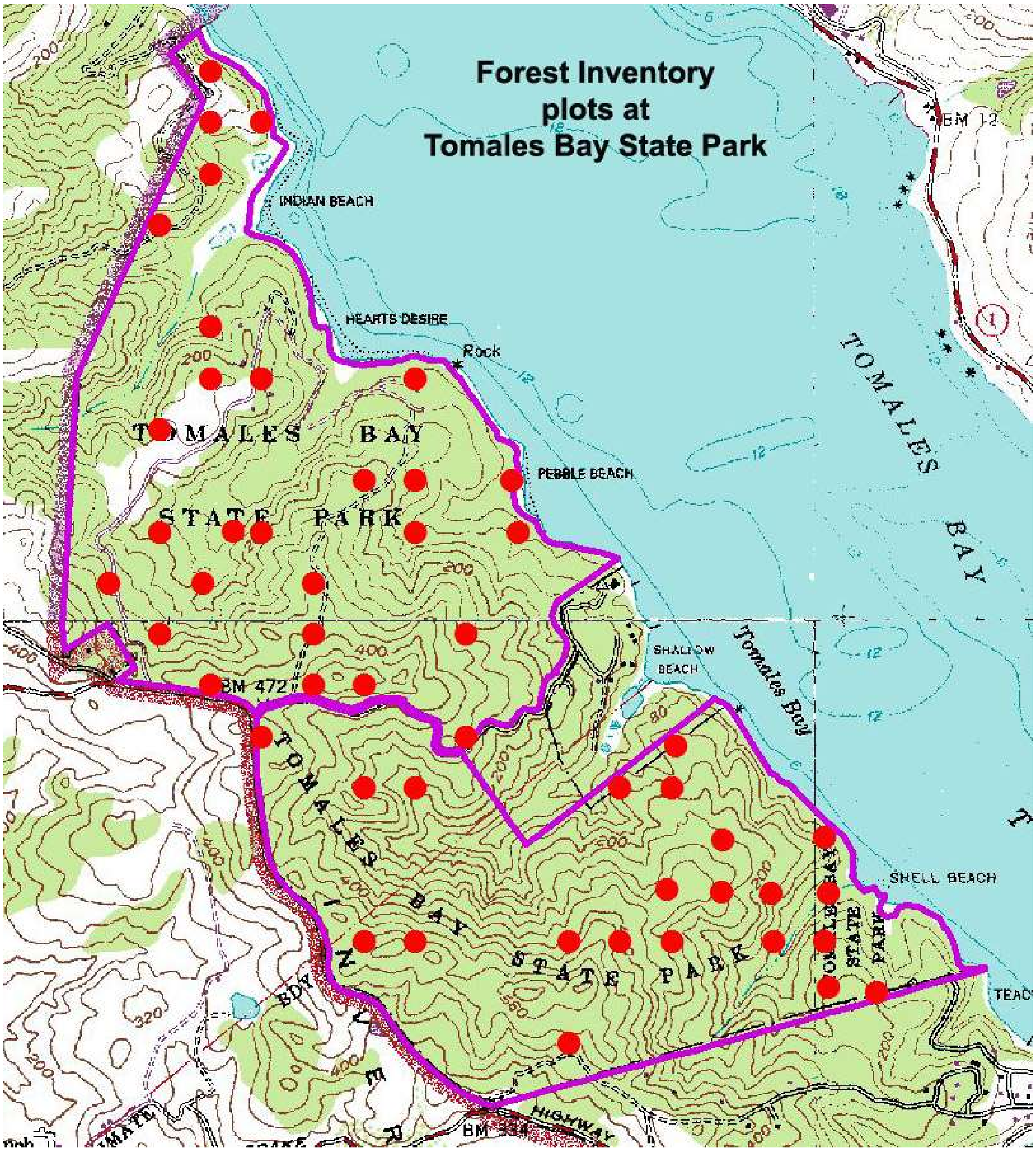

Figure 4. Fifty Forest Inventory Plot Locations

Forty-nine of the 50 plots were forested with at least a single tree The chart below (Figure 5) shows the basal area per acre, based on the averaged 50 plots combined, for trees measured including both hardwoods (coast live oak, tanoak, madrone, bay, alder and a few minor species) and conifers (99% bishop pine) by diameter class. It is notable that no bishop pine (green cross-hatching) was measured in the smaller size class categories and that most of the large mature "stocking" of the forest is large 20 to 30" diameter trees. This indicates that the forest is not readily recruiting young pines and that the trend is toward increasing dominance of the hardwood species.

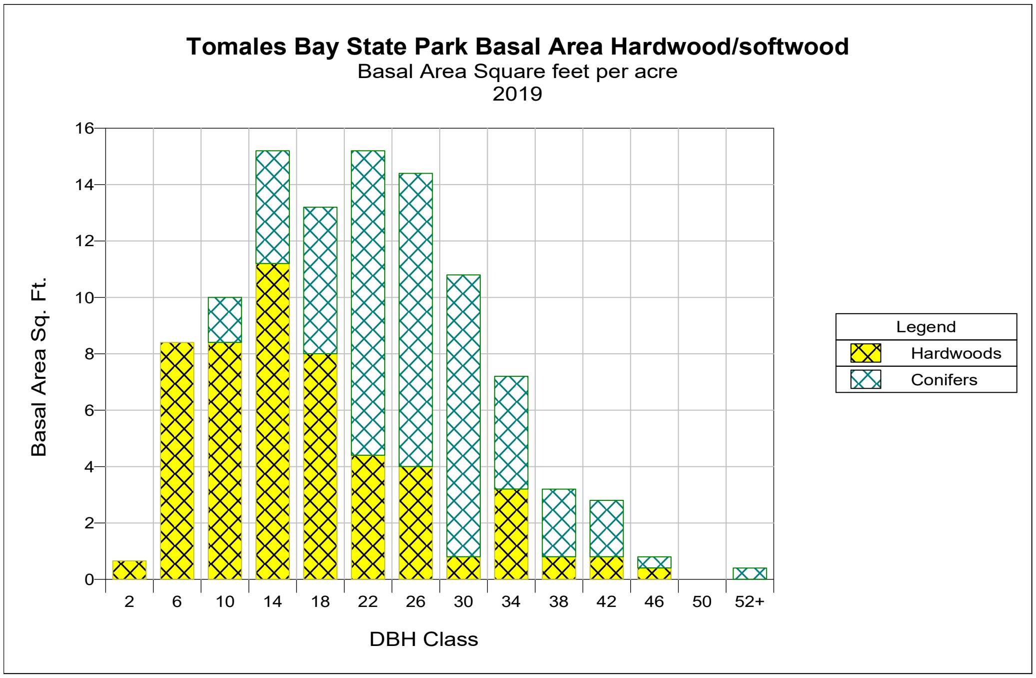

Figure 5. Basal Area by Size Class for Hardwoods and Softwoods (Conifers)

The histogram below (Figure 6) shows the number of trees per acre by diameter class, again for hardwood and softwood species. Note that there are about 30 small (2-4" DBH) hardwoods per acre and 55 trees per acre in the 4-8" size class and that bishop pine regeneration, again, is entirely lacking. Note also that there is a small number of very large trees both hardwoods and softwoods.

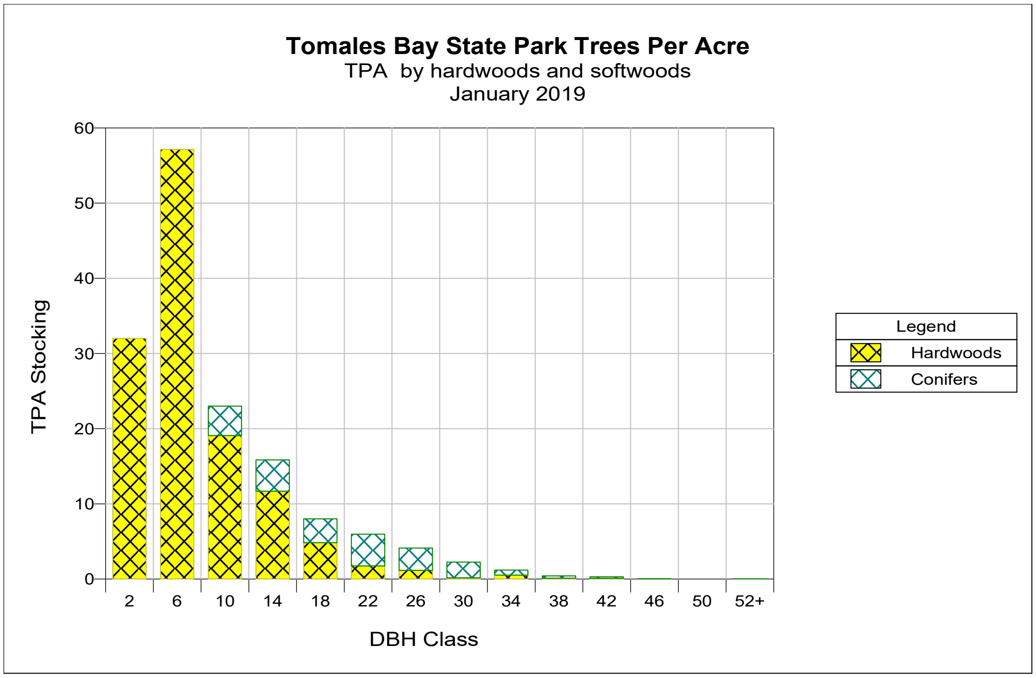

Figure 6. Trees per Acre (TPA)by size class for hardwoods and softwoods (conifers)

To further demonstrate species distribution, the histogram below (Figure 7) shows the basal area by size class and species. The dominant hardwood species at Tomales Bay State Park is coast live oak. Tanoak is diminishing due to the Sudden Oak Death pathogen that has been killing trees in the Inverness area since 1995.

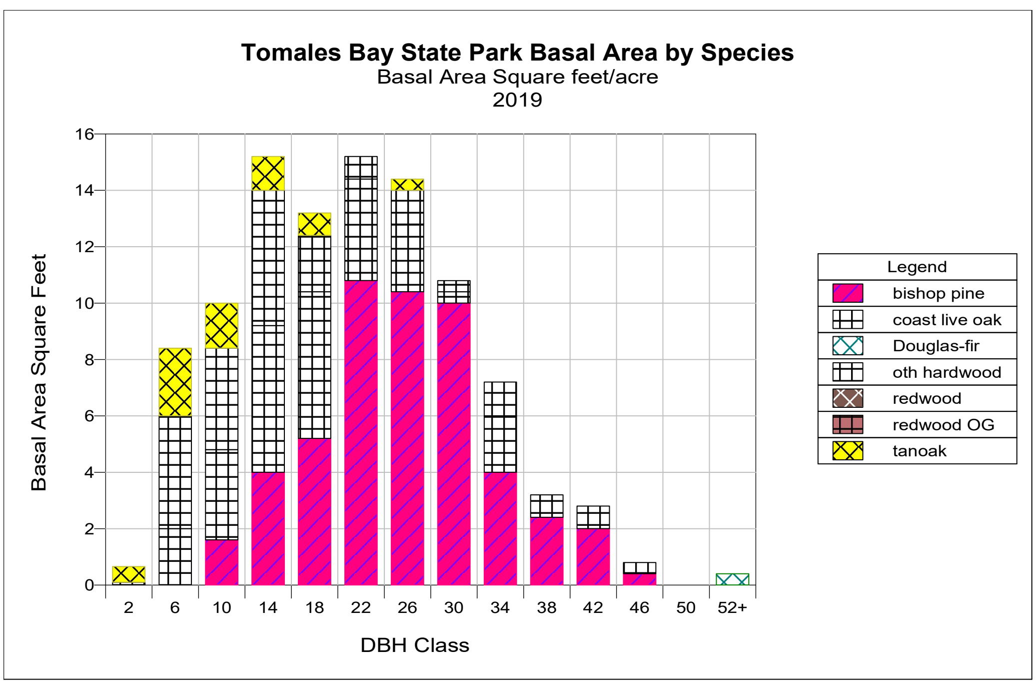

Figure 7. Basal Area by species and size class (DBH)

The histogram below (Figure 8) demonstrates the same information in terms of number of trees per acre by species.

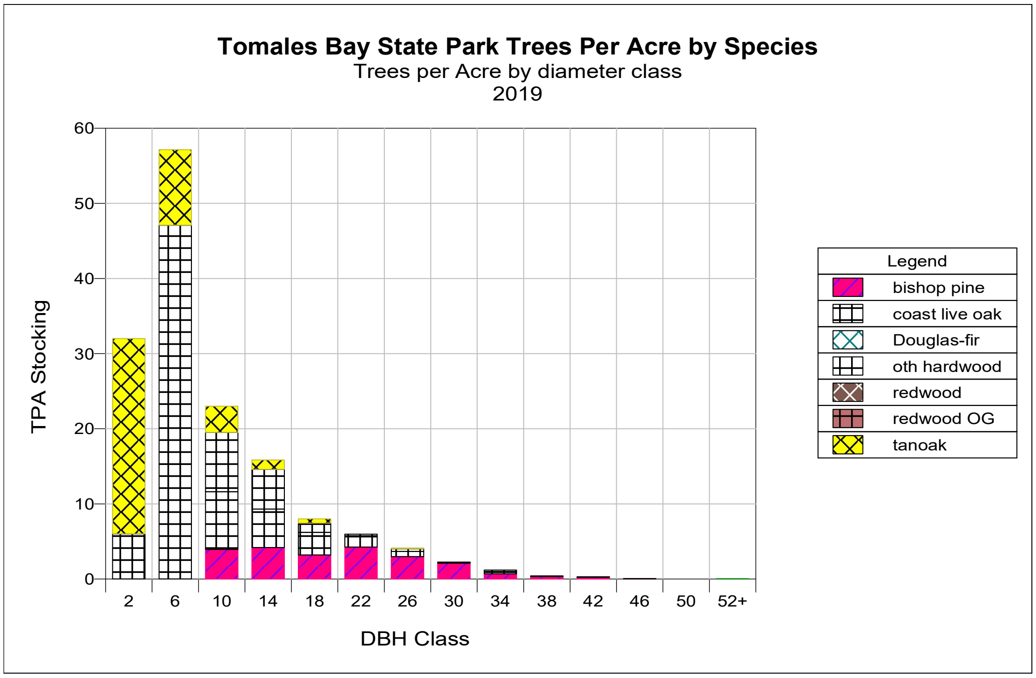

Figure 8. Trees per acre (TPA) stocking by DBH class by species

The unstratified FORSEE output below (Figure 9) is the base summary for the information presented above. An interesting observation is that the conifer live biomass is greater than the hardwood live biomass, totaling 1400+ cubic feet per acre, very low by California coastal forest standards (see the cubic feet metric in Figure 9). Noteworthy, a recent inventory of a partially cutover forest on the Sonoma coast showed stocking of 5576 cubic feet per acre (Douglas-fir and redwood) and 928 cubic feet per acre of hardwood (mostly tanoak and madrone), or more than 4 times the above ground live biomass at Tomales Bay State Park.

FORSEE Unstratified Output for live trees: 50 plots

Tomales Bay State Park

January 2019 per acre values for trees 1" and larger

Species	Stocking QMD	TPA	BA	Bf	Cf	CC
tanoak	5.5	41	7	129	51	0.13
other hardwood	7.9	53	18	730	279	0.29
Douglas-fir	53.0	0	0	84	13	0.00
coast live oak	11.9	34	26	785	314	0.35
bishop pine	20.7	22	51	3411	782	0.14
Conifers	20.7	22	51	3495	795	0.15
Hardwoods	8.5	128	51	1644	644	0.78
Totals	11.2	150	102	5139	1439	0.92

QMD = Quadratic mean diameter (sqrt(sigma(dbh^2)/#trees))
TPA= trees per acre
Bf = board feet
Cf = cubic feet
BA = basal area square feet
Cc = canopy closure

Figure 9. FORSEE tabular summary

Figure 10 below shows the basal area for each of the 50 plots with the hardwood/softwood components for each. Eighty percent of the plots have bishop pine present, indicating that bishop pine, as a species, is still well distributed throughout the park.

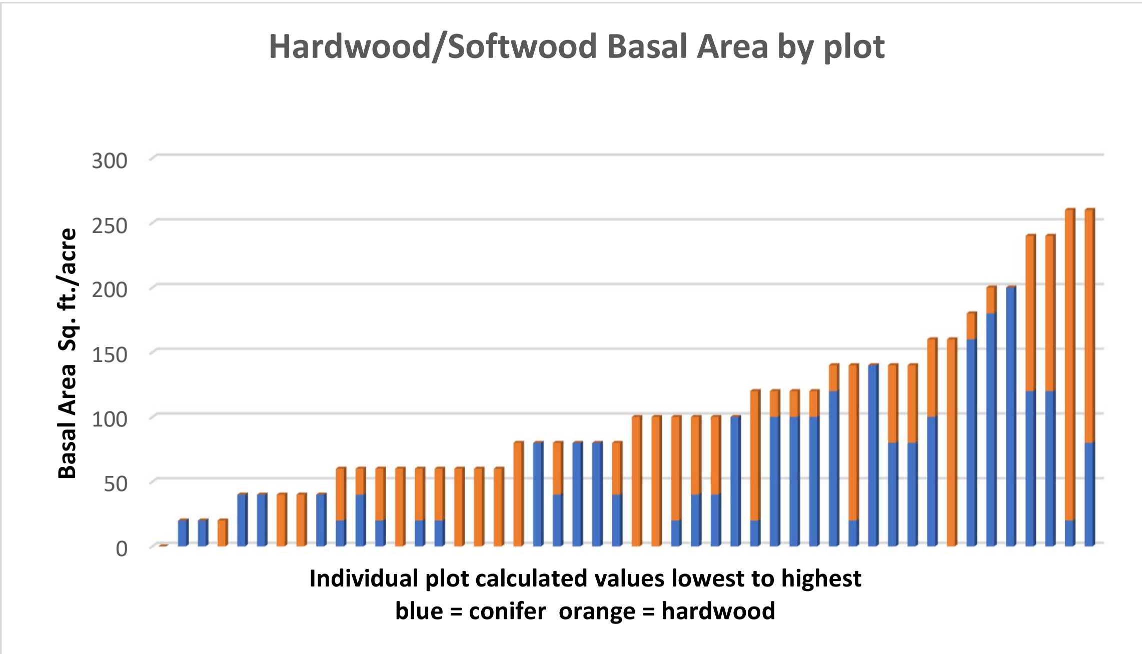

Figure 10. Hardwood and Softwood (conifer) Basal Areas for 50 plots.

Heights were recorded for every tree in the inventory. The scatter diagram below (Figure 11) shows that generally the bishop pines are taller than most of the hardwoods and the large trees range in height from about 45 to 85 feet. The one tree that is 130 feet in height is the very large Douglas-fir which occurs in relative isolation on decomposed granite soils.

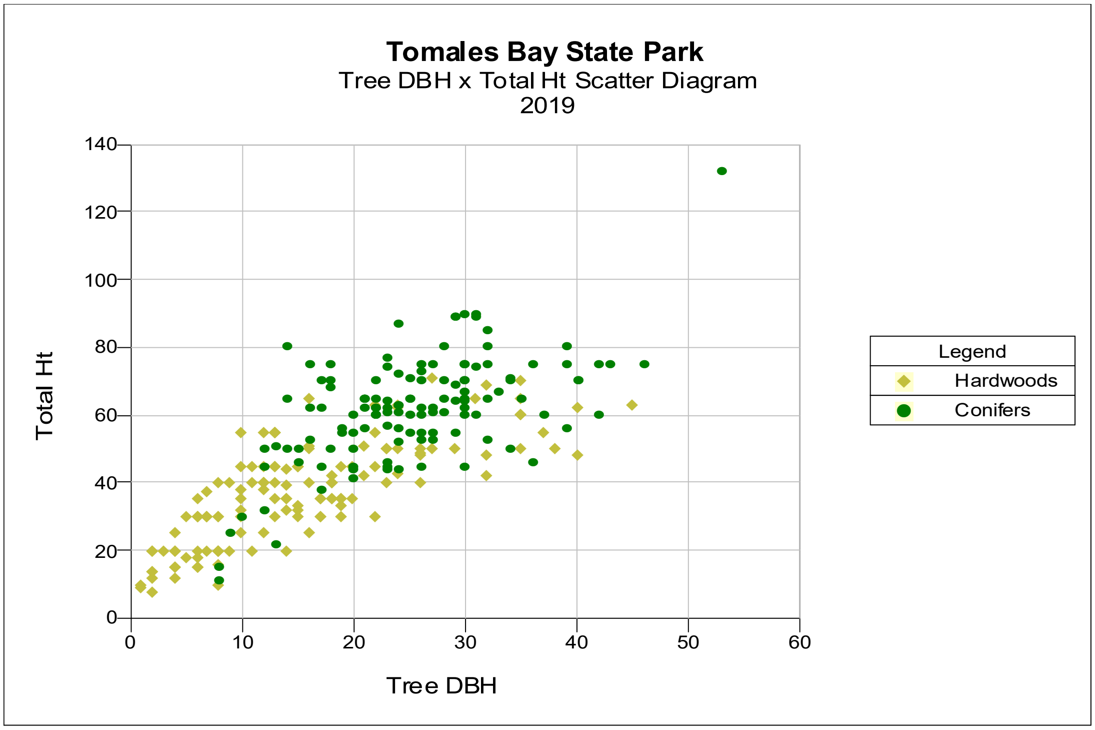

Figure 11. Inventory Trees' DBH & Height by Hardwood and Conifers

Forest Health and Pests

Bishop pine is a native tree susceptible to attacks from indigenous and exotic pests. Primary among those are pine gall rust, pitch canker and a variety of bark beetles including "ips", turpentine beetles and western pine beetle.

Pine beetle infestations normally are a result of other infestations or stresses such as soil compaction, drought, or even forest harvest. Pitch canker is a non-native fungal pathogen, which has become established in Marin County over the past decade[4].

Pitch canker has eliminated most of the young bishop pine forest at Point Reyes National Seashore overlooking Limantour Estero and much of the Monterey pine on the Monterey and San Mateo coasts. Bishop pine seedlings regenerated vigorously near Limantour Estero on droughty, burned sites with thin soils following the 1995 Vision Fire. Conversely the Tomales Bay State Park bishop pine forests are generally sited on deeper soils with more abundant rainfall, and pitch canker, although in the area, has not yet severely affected the forest.

Pine gall rust canker, however, is a gall canker that has been in the area for many generations of forests. The gall rust canker infects the stem and branches of young pines but does not normally kill the tree. The branches and stems, however, are weakened. Although the tree stem may grow over and hide a wound, the tree structural damage is

[4] See https://www.nps.gov/pore/learn/management/upload/SFSU_Pitch_Canker_Poster_2009.pdf

ongoing. The cankers create weak points with greatly increased vulnerability to mechanical breakage exacerbated by wind. Twenty-four (24) out of 128 live bishop pines measured on plots, or 18.8%, showed signs of severe gall rust canker damage, affecting an average of 24% of the total volume of each tree.

Dwarf mistletoe (*Arceuthobium campylopodum*) is an obligate parasite that affects live conifers throughout the west, including most species of the genus *Pinus*. It manifests in swollen branches and tree stems and has a unique foliage. Although present at Tomales Bay State Park it does not appear to be a major forest health problem.

Tan oak and coast live oak are both impacted by Sudden Oak Death (SOD) (*Phytopthora ramorum*), which was first identified nearby in 1995. Tan oak is 100% vulnerable and coast live oak shows some resistance. While there are some remaining tan oaks at Tomales Bay State Park, most have already been infected and killed by SOD. Hardwood forests near walking trails have been particularly impacted in the areas of Shell Beach, the southern portion of the Johnstone Trail and along the Jepson Trail.

Figure 12. Severe SOD mortality has transformed the low-elevation forests near Shallow, Shell and Heart's Desire Beaches. This photo was taken near plot 19.

Forest Inventory Representation by Individual Plot

The maps below depict the total basal area per plot (Figure 13) and number of trees per acre (separately by conifers (Figure 14) and hardwoods (Figure 15)) for each plot in the inventory. These maps will be helpful for management planning, as there is great variability in stocking and species composition that will spatially affect (stratify) the management planning process.

Figure 13 depicts total basal area of all trees in all plots, which indicates the heaviest stocking is in the areas surrounding Shell and Heart's Desire Beaches.

Figure 14 shows the relative abundance of bishop pine by plot. Note that most of the bishop pine are located in plots on hillsides and hilltops at the southern and central portions of Tomales Bay State Park. Likewise, Figure 15 shows the abundance of hardwood trees by plot.

Tomales Bay State Park Forest Inventory 2019

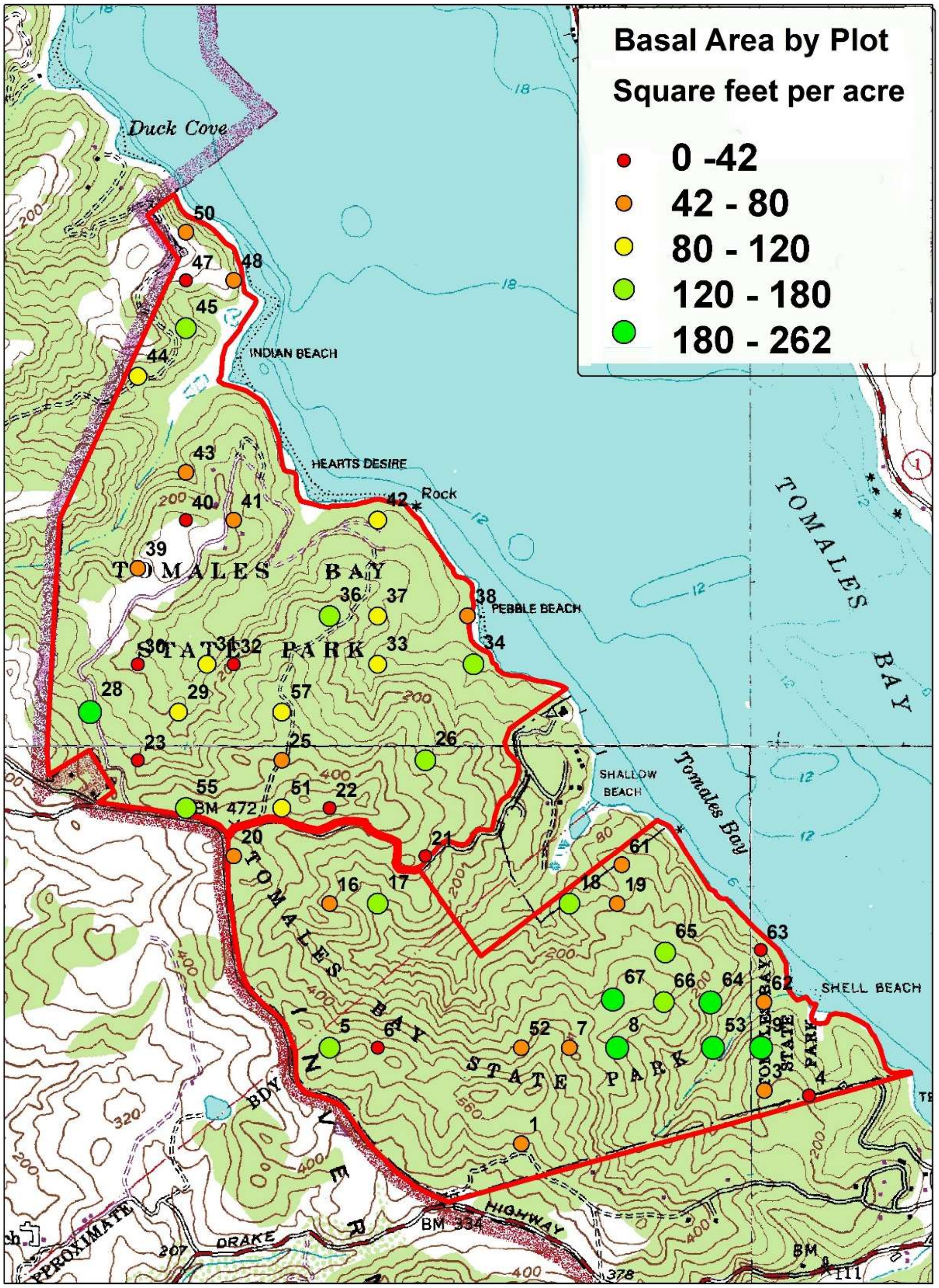

Figure 13. Total Basal Area by plot in square feet per acre.

Tomales Bay State Park Forest Inventory 2019

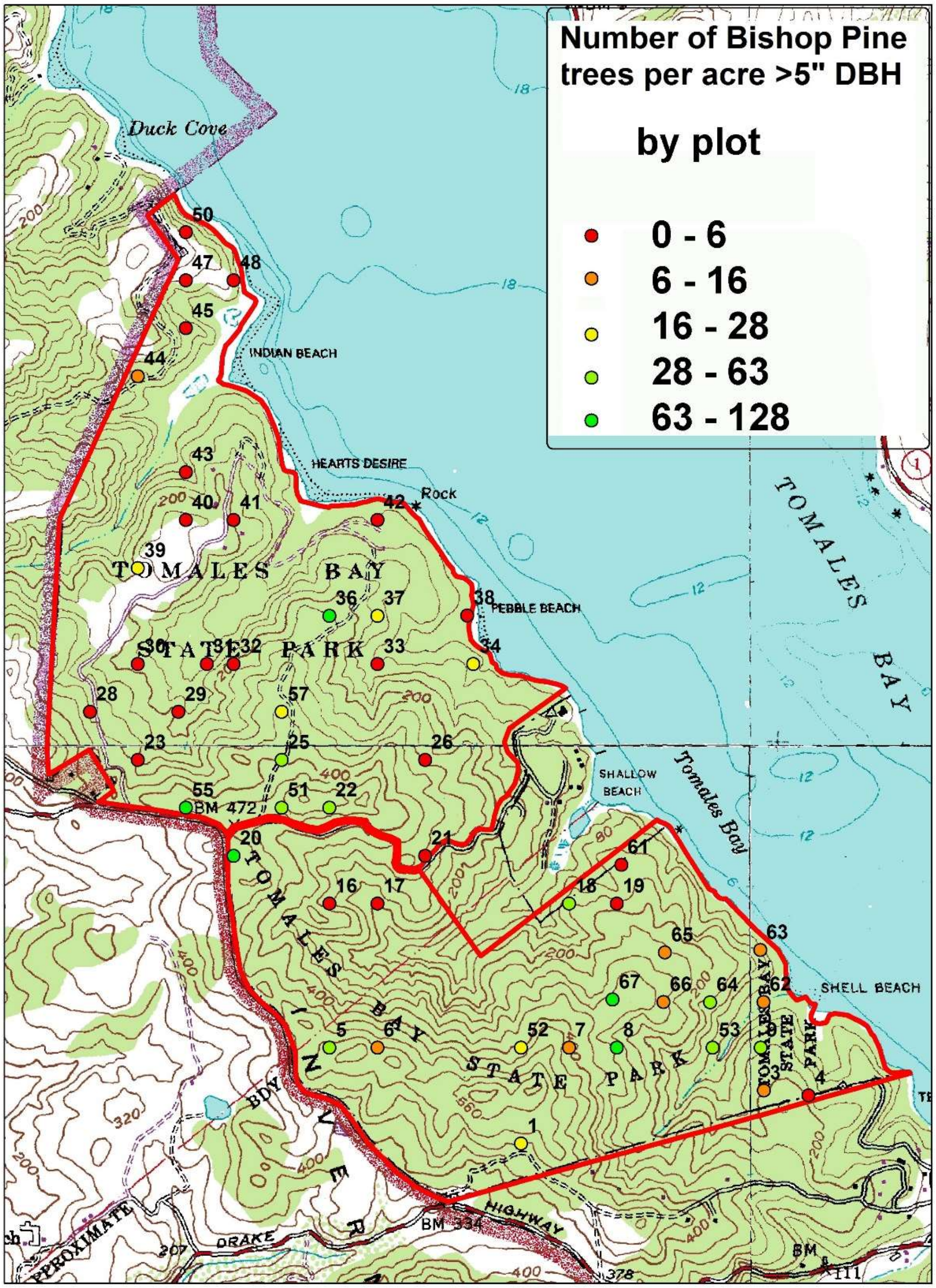

Figure 14. Number of bishop pine trees per acre by plot

Tomales Bay State Park Forest Inventory 2019

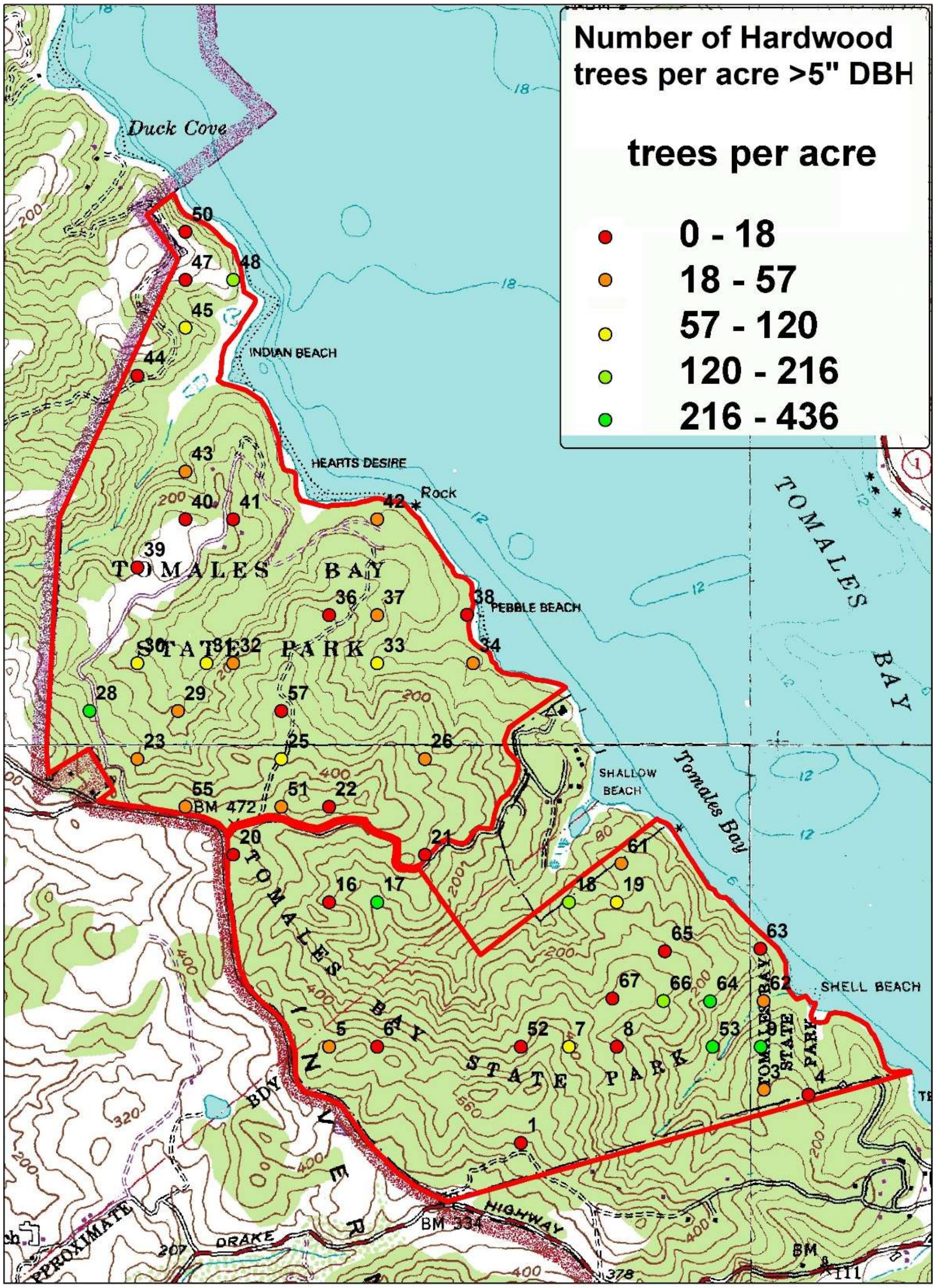

Figure 15. Number of hardwood trees per acre by plot

Forest Regeneration

Seedings on 1/100-acre circular plots surrounding each plot's center point were observed on 23 of the 50 plots (46%) (Figure 16). A single bishop pine seedling, growing in a disturbed area alongside a trail, was observed on Plot 18. All other seedlings observed were hardwoods which grew from seed or sprouts. Overall, there is an average of 2 pine seedlings and 100 hardwood seedlings per acre. The data indicate that reliance upon natural regeneration will not result in a sustainable bishop pine forest at Tomales Bay Park. Note also that tanoak seedlings are not expected to survive due to mortality associated with *Phytophthora ramorum*, the pathogen that causes Sudden Oak Death. Coast live oak seedlings do occur and, along with California bay seedlings, some can be expected to survive.

Tomales Bay State Park Forest Regeneration	
Species	**# trees/acre**
Bishop pine	2
Madrone	4
Chinquapin	4
Tanoak	60
Coast Live Oak	20
California Bay	12
TOTAL per acre	**102**

Figure 16. Forest Regeneration: Seedlings per acre on fifty 0.01-acre plots.

Forest Canopy Closure

FORSEE calculates overlapping canopy closure based on the actual live tree inventory. This means that canopy closure of forest trees, which normally have overlapping crowns, may add up to well over 100%. The bishop pine forest at Tomales Bay State Park covers 15% of the canopy area while hardwoods utilize 75% of the canopy. In Figure 16 the "cartoon" representation of the forest inventory shows bishop pine in bright green, coast live oak in dull green, tanoak in tan and other minor species in other colors. It represents average size and density (trees per acre). Note that the open canopy cover leaves plenty of room for sunlight to access the understory layers, which would include small trees, shrubs, forbs and grasses. The forest representation in Figure 17 shows the canopy of the forest with many open areas where the sunlight is utilized by the shrubs, ferns, and grasses.

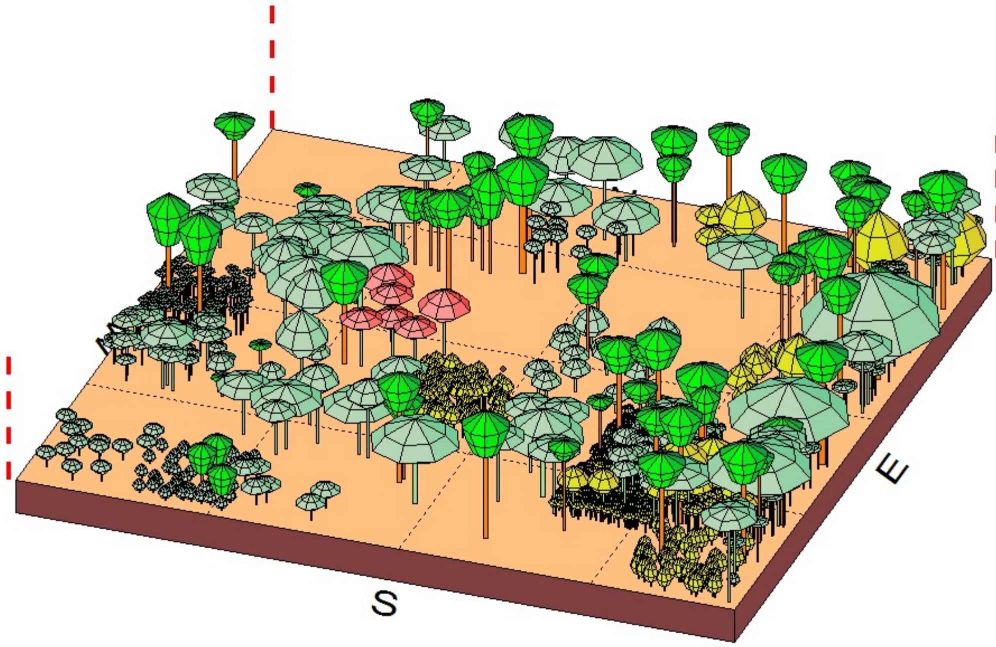

Figure 16. Forest Representation: Bishop pines are shown in bright green whereas hardwood species are shown in the remaining colors. Note the hardwood regeneration shown by small trees.

Shrub and Grass Cover

On each plot, ground cover was estimated in the understory canopy layers (Figure 18). Throughout the park, shrub cover overwhelmingly occupies the understory and open canopy areas. On some plots, perennial grasses were also present. The chart below shows the shrub and grass cover for each plot.

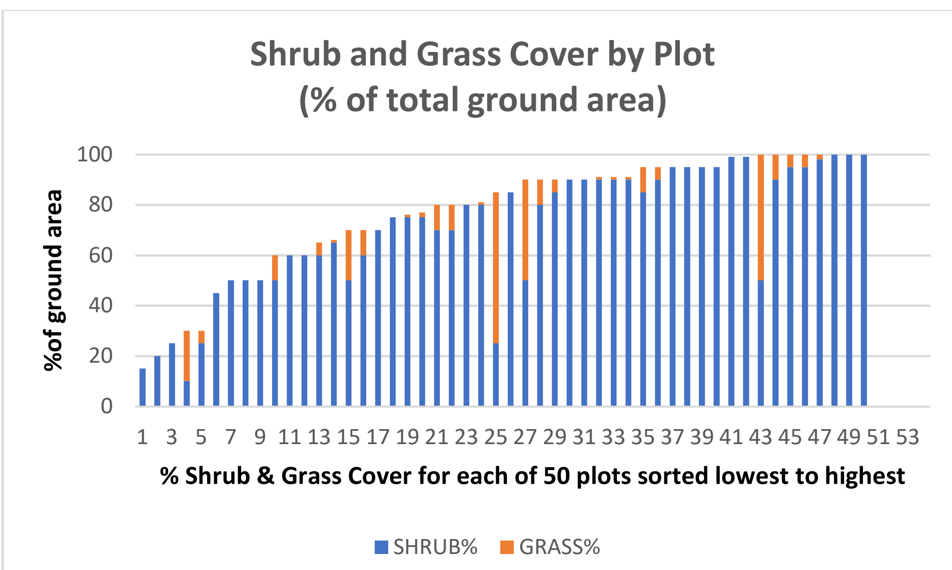

Figure 17. Shrubs and grass layers cover almost all of the understory area on most plots

Standing Dead Trees

The chart below (Figure 19) expresses the live trees' (hardwood and conifer) basal area for each plot, and in gray, the unspecified standing dead component of the forest at Tomales Bay State Park. There is an alarming number of standing dead trees, which are recent mortality. Primarily these are dead bishop pines. Most of the tanoak and coast live oak mortality that has resulted from Sudden Oak Death has fallen and is rapidly rotting on site. Bishop pine mortality is primarily due to decline associated with pine gall rust canker coupled with beetle infestations and the recent drought.

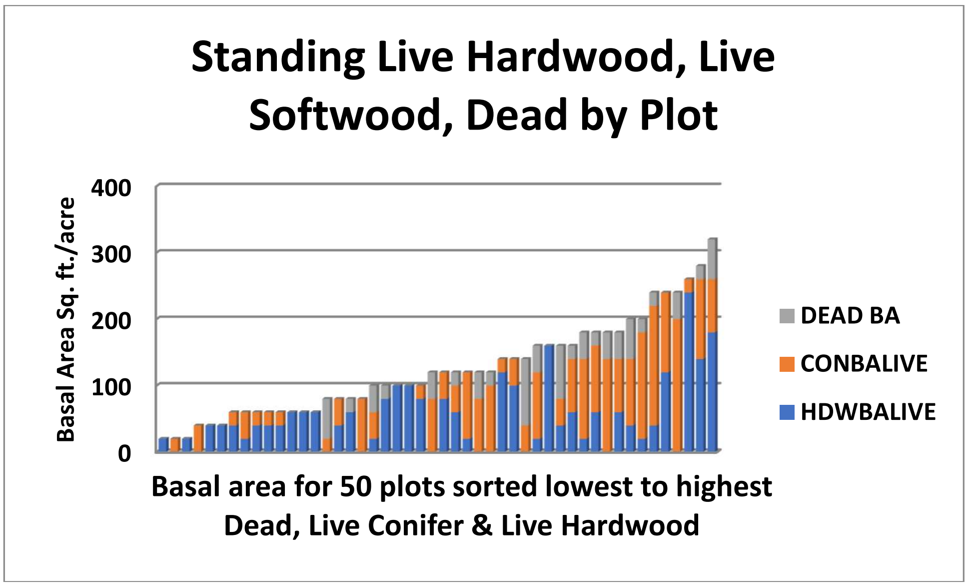

Figure 18. Live & Dead Basal Area (BA) for standing trees by plot

Lying Dead

Lying dead wood and logs more than 8" in diameter and greater than 8 feet in length were measured on each 1/24th acre circular plot surrounding the center point. The average woody debris was 25 down logs per acre averaging 17' in length. Many plots are so thickly vegetated by dense shrubbery that it is impossible to see all the down logs in the ground debris layer, and so the 25 down logs per acre is certainly a low estimate. Seventy percent of the down logs measured were bishop pine, followed by tanoak, coast live oak, madrone and chinquapin.

Brown's Transects

The inventory included a Brown's transect for fine woody fuels including flash fuels (0-25" DBH), medium fine fuels (0.25" to 1" DBH) and coarse fuels (1-3" DBH).

Figure 20 below shows the distribution of the down woody debris in tons per acre

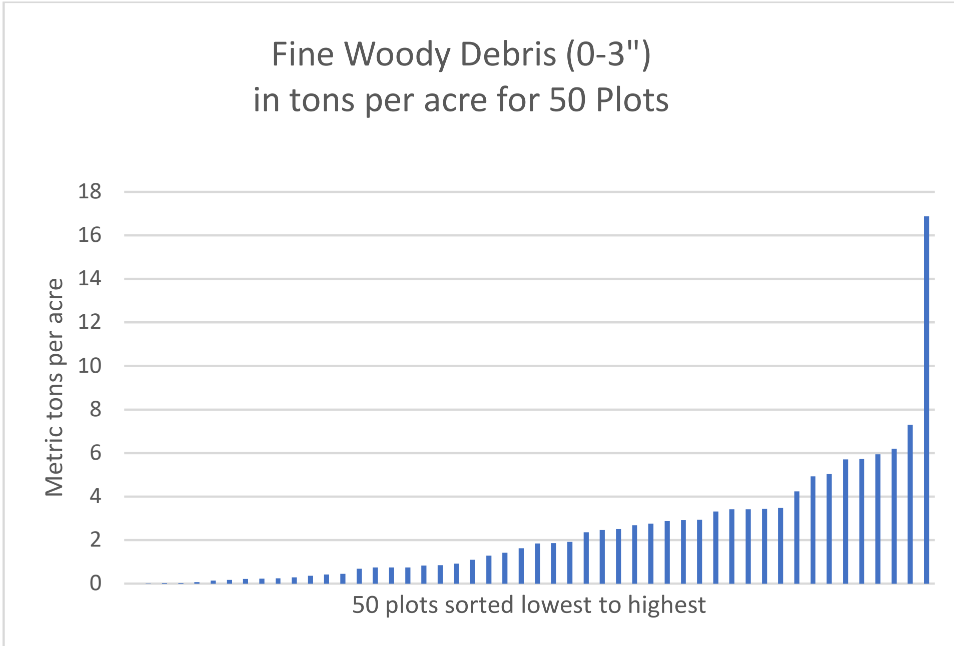

Figure 19. 0-3.0" Down Fine Woody Debris per plot in tons per acre

which is not excessive, almost uniformly 6 tons per acre or less. Fine woody debris twigs and small diameter branches, mostly bishop pine and tanoak, rot so quickly under the seasonally moist conditions that such material rapidly integrates with the duff and litter layers.

Duff and Litter Depth

As forest trees shed needles, leaves and woody debris, these organic components biodegrade and accumulate in the understory. This process creates two important layers on the forest floor: 1. The litter layer consists of identifiable debris; 2. while the duff layer, immediately below the litter and above the mineral soil layer, consists of organic debris, which has decomposed beyond the point where individual leaves, sticks, needles or other organic materials are readily identifiable. The duff and litter depth were measured by digging a hole extending down to mineral soil. These holes were located at the undisturbed end of the Brown's transect, normally 24' north of the plot center. Essentially all plots had measurable duff and litter. The litter layer, for all plots, averaged 1.9" on top of an average duff layer of 2.9". This means there is an average of almost 5" of organic material covering mineral soil throughout this bishop pine forest. Therefore, in the absence of disturbance, seeds are unable to access mineral soil and they do not germinate. Also, in the absence of disturbance (such as fire) trees that do not sprout, such as bishop pine, are eliminated from successive generations of forest trees.

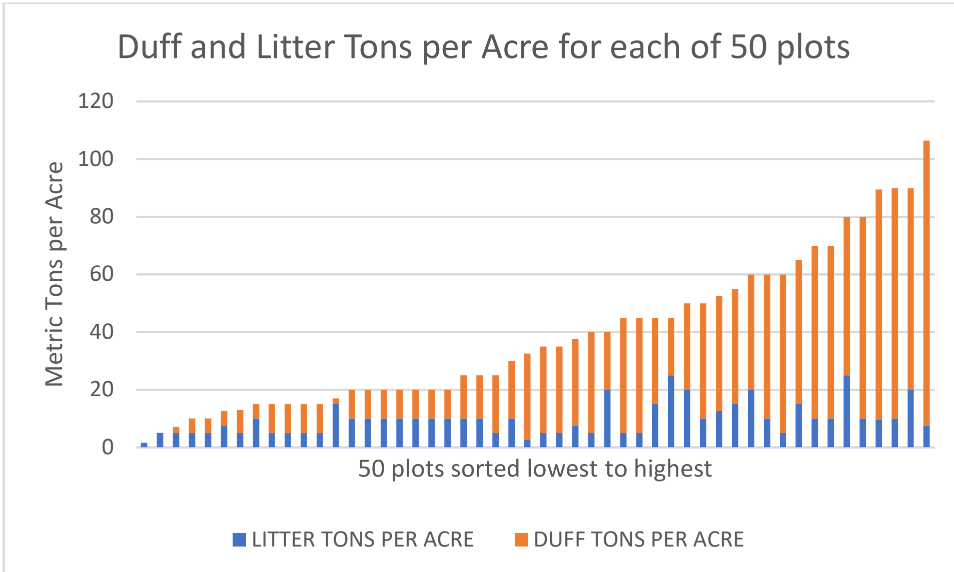

Figure 20. Duff and Litter tons per acre by plot. Duff and litter layers ranged from 2" to 12" in depth

Carbon storage

Biomass translates directly to sequestered carbon and carbon dioxide equivalents. Trees store carbon above and below the ground. FORSEE calculates carbon stocking for every tree in the inventory and then expands those to per acre and total stand values. Figure 22 below indicates carbon dioxide equivalents for above and below ground forest carbon in live trees per acre and for 962 acres of Tomales Bay State Park. These are calculated using the California Air Resources Board 2013 equations.

Species Group	Stem Mg per acre	Total_Mg for TBSP
bishop pine	25.0	23919
coast live oak	26.0	24791
Douglas-fir	0.3	375
other hardwood	12.5	12055
tanoak	3.5	3394
Conifers	25.2	24295
Hardwoods	41.8	40241
Totals	67.1	64536

Figure 21. Carbon dioxide equivalent storage Megagrams (metric tons) per acre and totals for 962 acres

Discussion: Forest Fuels & Forest Management Alternatives

The forest inventory at Tomales Bay State Park has demonstrated that the iconic bishop pine and some hardwood forests are declining or not sustainable without additional management, and thousands of trees are rapidly dying out without sufficiently regenerating. Forest woody debris (known as "1-hour", "10-hour" and "100-hour" fuels in the forest fire community) and "ladder fuels" have accumulated throughout the park. Deep layers of litter and duff would further inflame conditions in any wind-blown wildfire.

Hazardous and extreme forest fire weather conditions occur during periods of low relative humidity and low fuel moisture content when winds drive fire. There are many points in the park where ignition of a forest fire could occur. Fuels reduction work in high probability ignition areas such as along roads, around picnic areas and structures, and along the park's southern boundary would reduce fuel loads in probable high ignition areas.

The Tomales Bay State Park General Plan of 2004 Plant Communities goal is to "Manage for the enhancement and perpetuation of native plant species diversity and the biological and compositional integrity of native plant communities". While serving this goal and reducing forest woody fuels, there are several site-specific options that can be considered conjunctively, all of which require planning and expenditures for fuels reduction and forest management. These options include carefully planned prescribed fire in strategic areas during periods of low fire hazard conditions. Prescribed burns normally start with very small and confined "test burns" and are quite limited in size, but they break up the continuity of forest fuels and are effective at reducing fire hazard and improving forest health. Such treatments can be applied on the landscape by professional fire agencies. As an example, Calfire has its "Vegetation Management Program" (VMP) which utilizes the professionals of the fire-fighting community and serves to protect communities exposed to high wildfire risk. Other methods to reduce forest fuels include mechanical removal of dead trees, reduction of shrub cover (utilizing a carefully shepherded herd of goats, for instance) creation of large "shaded fuel breaks" along access roads and trails, elimination of ladder fuels, and ground-level scarification to disrupt the continuity of duff and litter layers. All these methods can be used in combination with each other.

There are well-tested computer models available free online, such as "BehavePlus" and "FOFEM", which utilize a variety of input variables (slope, aspect, fuel bed, fuel type, vegetation type and condition, wind, relative humidity, fuel moisture, local climate, time of year, season, etc.) to characterize the behavior of prescribed and wildfires under varying weather conditions. When used in combination with geographic information systems (GIS) such models are helpful for planning prescribed fire or when used by wildland firefighters.

The other element of sustaining the bishop pine forest at Tomales Bay State Park is the reestablishment of a new generation of bishop pine and other native forest species. This can be accomplished through thoughtful silvicultural treatments, including prescribed fire. When carefully planned and implemented, mechanical exposure of bare mineral soil promotes natural bishop pine regeneration. Protection of areas with large healthy trees and vigorous forest growth, and strategic plantings (known as artificial regeneration) are very effective. All these management options must be undertaken with detailed planning and within the context of protection of critical habitat, environmental quality and natural resources.

This report provides a detailed starting place and baseline to initiate restorative activities based on informed decisions, but restoration planning is beyond the scope of this project. A recommended next step is to select and map prioritized areas, and then to identify methods for forest management, protection or renewal and fuels reduction. At the same time State Parks can initiate the planning and budgetary processes for implementation of sustainable forestry for this rare and important public forest park.

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Appendices

Tomales Bay State Park Forest Inventory Specifications

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Part 1. Introduction

The purposes of the Tomales Bay State Park forest inventory will be to quantify extent of forest health, forest fuels, and to help inform development of management prescriptions in bishop pine and mixed evergreen forests. The field inventory includes plot level data and an inventory of individual trees.

The plot-level forest health indicators include forest type, size and density, a 24' Brown's transect (on each plot) which will enable quantification of fine, medium and coarse woody fuels, duff and litter layer depth to bare mineral soil, and an assessment of the shrub layer. A series of photos will be taken in cardinal directions on each plot, starting with north. The fifth photo will be of the ground cover on the transect (also north).

The tree inventory will include live tree species, diameter, height, crown class and health/damage for all trees greater than 5"in diameter at breast height (dbh). Seedling and saplings will be recorded as indicators of forest regeneration. A number of site trees will be measured. The inventory will include tree mortality (standing and lying dead), forest woody and other organic fuels, damage to residual live trees, shrub and grass cover, and associated notes and commentary.

The sample may be post-stratified based on forest type. The plots were selected at random from a grid of plot locations each located 163 meters in cardinal directions from the adjacent plots. Fifty plots shall be measured. If a plot is not accessible in reasonable time and with reasonable effort, then an alternate will be selected from the grid. If a plot falls in a non-forest area its location may be adjusted in a cardinal direction to a nearby location in multiples of 25 meters distant from the invalidated plot location.

The data recorder will prompt for all information. The Alpha Codes in CAPITAL letters are the default values. Lower case prompts indicate the other possible choices.

Use the dedicated program (carbon6.exe) to collect field data, which will then be correctly formatted by the data recorder software. Number all plots using the map plot numbers shown on the map or GPS. The plot data will be found in the Husky data recorder directory "C:\CT9\DATA". The Husky will be downloaded daily.

The plots will be located using the GPS waypoint gpx file provided and uploaded to the Garmin GPS. When about 10 meters from the plot use compass and laser range finder to target a plot center so that plots are located without bias. Record Garmin waypoints for any alternate plots measured.

Part 2: Plot Methods

Referencing the Tree plot. Place a wooden stake and aluminum nail at each plot center. Hang biodegradable orange flagging nearby. Enter the data as prompted in the data recorder.

a. Tract Level Data ('T' at main menu):

Tract name: Tract or file name (unique each day as and identical tract/file name will over write existing data in the data recorder, if it exists. It **is very important to use 5 digits only: initial/(mm/dd/(alpha)** e.g. 1226b).

Unit area: record '5'. The fixed area plots are 24' in diameter or 0.04 acres.
Crew Initials: record up to 4 digits.

Date: mm/dd/yy

BAF 20 for this inventory 1.945 * dbh in inches equals the horizontal distance in feet to edge of variable radius plot (the center of the tree at breast height). The data recorder can be used to calculate maximum distance to face or pith (center) of prism variable radius plot trees on any slope. All live trees greater than 2.5" diameter and dead trees greater than 5.0" are recorded using the 20 BAF prism.

b. Plot level data to be recorded ('P' at main menu).

Record plot Calveg type, size class and density class
Plot number (from Garmin or map)

Slope (percent)
Aspect (degrees)

CALVEG Designation:

Primary Canopy Type Code: Plot Dominant Species (bishop pine, Douglas-fir, Mixed, Hardwood or Other)

Plot Conifer Dominant Size (1 seedling, 2 poles, 3 small sawtimber, 4 larger st, 5 old growth

Plot Conifer Dominant Density (S (0-25%),P (26-40%),M(41-60%),G (61-100%)

Transect Data. This is a 20' transect recorded from 4' north of plot center to 24' north of plot center. At the 24' point a hole is dug to bare mineral soil and litter and duff depth are recorded in 10th of inches (e.g. 40=4"). The number of 0-1/4" sticks, ¼" to 1" sticks, and 1" to 8" sticks is recorded per the prompts for fine, medium and coarse woody debris.

Shrub and Grass cover on 1/24th acre is an ocular estimate. Record shrub species and heights in plot-level notes.

Percentage of plot in 1/24 acre. Use the default unless a portion of the plot falls outside forest perimeter. This is normally 100 (percent).

Photo: Record 5 photos from each plot center in cardinal directions plus a 5th photo of the ground cover on the transect which always faces north. Reference the plot number in the lower left corner of the photographs on the white board. Submit the photo files with the plot data.

c. Tree Level Data ('R' at main menu):

Plot measurement specifications:

1/100-ac plot for seedlings (6" tall to 0.5" dbh) counted by species (RECORD TYPE 8)

20 Basal Area Factor (BAF) prism plots for live (STS = 0) and dead trees (STS=1) 3.0" and larger.

1/100 acre (11.8' radius) for saplings 0.5 - 2.5" DBH.

1/24th acre fixed area plot for Coarse Woody Debris greater than 8" at the small end. The big end must be within the fixed area to be measured. Make ocular estimates of diameter, length and species and decay only. These are biodiversity indicators and will be used for quantifying coarse woody fuel and forest mortality.

Data Entry:

Tree Status: Live Trees (Status 0). Standing dead, Lying dead (status 2). Seedlings (status 8).

Live trees (status 0) and standing dead trees (status 1) are measured in this inventory. Down woody debris (status 2) and vegetation layers are also inventoried. Live trees, standing dead and lying dead, seedlings and saplings all get individual tree records.

Live (0) and Dead Trees (1) 3.0" and greater are measured using a 20 BAF variable radius plot starting clockwise from north

.

Species: Use the species codes as shown on the table below. Use alpha codes (upper or lower case is acceptable), or FIA number codes as indicated (use 212 for old growth redwood and 203 for old growth Douglas-fir). If you need a prompt enter "0" in the species field and a list will pop up.

Table 1. Species Codes: use FIA or ABBREVIATED CODES. Note not all of these species are or will be present on the Tomales Bay State Park.

Key to Species Codes

Cd	FIAcode	Species Common Name
SOFTWOODS		
GF	17	Grand fir
SS	98	Sitka spruce
SP	117	Sugar pine
BP	120	bishop pine
PP	122	Ponderosa
DF	202	Douglas-fir
DO	203	Douglas-fir Old Growth
RW	211	Redwood old growth
RO	212	Redwood old growth
RC	242	Western redcedar
WH	263	Western Hemlock
CX	299	Other Conifer
HARDWOODS		
BM	312	Big Leaf Maple
RA	351	Red Alder
MD	361	Pacific Madrone
GC	431	Golden chinquapin
PD	492	Pacific Dogwood
OA	542	Oregon Ash
TO	631	Tanoak
BC	747	Black Cottonwood
CH	768	Cherry
WI	920	Willow
XX	998	Unknown (mostly Bay 981 in this inventory)
HX	999	Other Hardwood

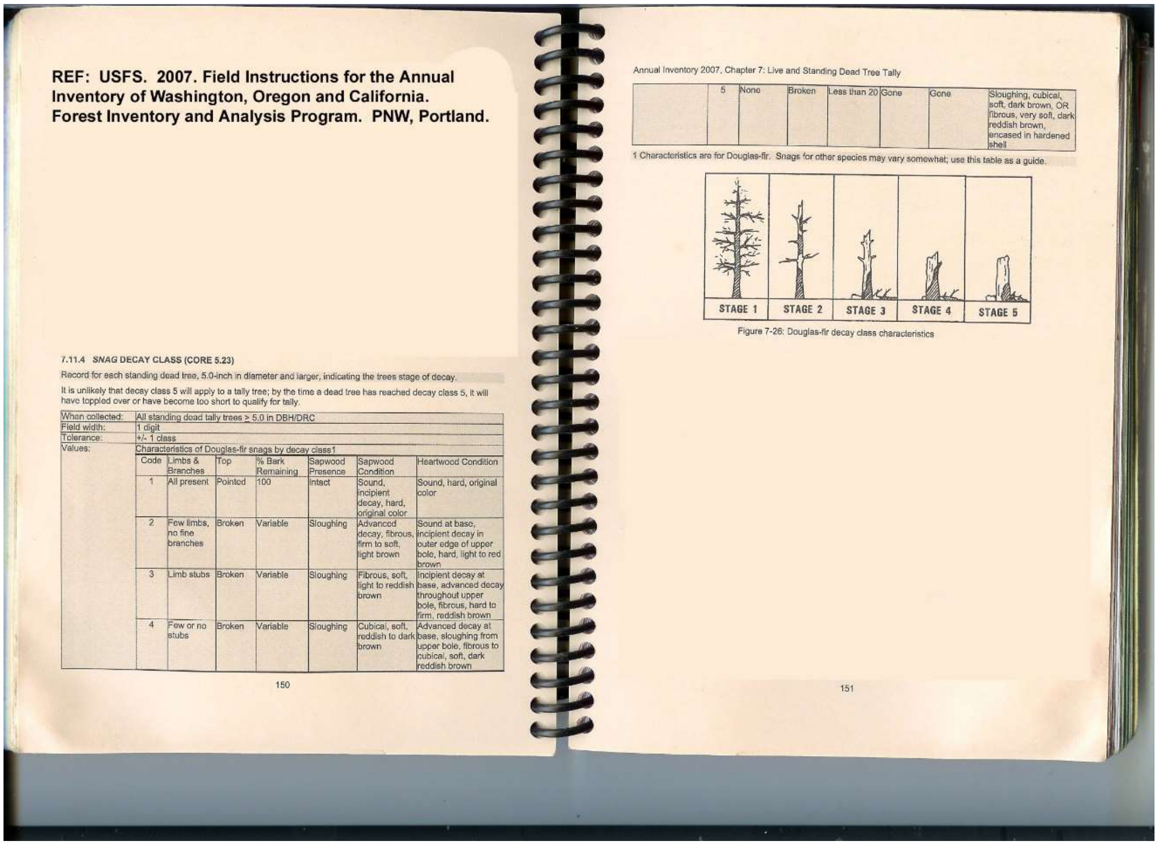
Diameter is measured using DBH to the nearest inch. Each fork of any tree with pith intersection below DBH is measured as a separate tree per FIA specifications (USFS 2008).

Hardwood trees with multiple stems are measured as individual tree records using the root mean square (RMS) method (sometimes recorded as DRC in the notes). Record the individual stem diameters for such trees in the tree-level notes. This is a departure from FIA standard methods. The reason for this is that we want to obtain a more-accurate count of hardwood trees irrespective of form.

Site Trees will be cored for age and growth increments (10 and 20 years). Species (mostly bishop pine), diameter and height will be recorded for each site tree, selected occasionally during the inventory.

Total heights are recorded for all trees on every plot. For dead trees the actual height and projected total height (per FIA specs) shall be recorded. Measure or estimate the total height of the tree (if it is missing the top, estimate the **total** height and put in the volume missing when prompted (missing or cull ROTTEN cull is recorded as % deduction: e.g. 70 means 70% of the tree is missing), and use the defect codes 0 (no defect), 1 (broken top), 2 (rot), 3 (rough form) and 4 (SOD), 5 (Gall rust Cankers) as prompted in the data recorder. Dead or broken top (defect code 1) is very important.

Crown: % compacted Live Crown Ratio per PNW FIA specs
Position per PNW specs (2 Dominant,3 Codom,4 Intermediate or 5 Suppressed)
Saplings (Status 0), identified by diameter class (1, or 2): 0.5-2.5 inch diameter trees are recorded on the 100th acre plot. All we need is species, DBH class (2), total height if applicable, live crown ratio, and number of trees in the category. Ignore 1-5 inch standing dead trees.
Seedlings. (Status 8) in tree file. Only the species and number of seedlings 6” height to 0.5” DBH on the 1/100 acre plot. Record a maximum of 20 seedlings of each species.
Dead Trees (Status 1) 3” and larger in DBH and 15’ or more in height are recorded using the 30 BAF plot and as instructed by the data recorder. Do not record dead trees on the 1/100 acre seedling/sapling plot. Record decay classes per USFS specs indicated in the chart below:



REF: USFS. 2007. Field Instructions for the Annual Inventory of Washington, Oregon and California. Forest Inventory and Analysis Program. PNW, Portland.

7.11.4 *SNAG* DECAY CLASS (CORE 5.23)

Record for each standing dead tree, 5.0-inch in diameter and larger, indicating the trees stage of decay.

It is unlikely that decay class 5 will apply to a tally tree; by the time a dead tree has reached decay class 5, it will have toppled over or have become too short to qualify for tally.

When collected:	All standing dead tally trees ≥ 5.0 in DBH/DRC
Field width:	1 digit
Tolerance:	+/- 1 class
Values:	Characteristics of Douglas-fir snags by decay class1

Code	Limbs & Branches	Top	% Bark Remaining	Sapwood Presence	Sapwood Condition	Heartwood Condition
1	All present	Pointed	100	Intact	Sound, incipient decay, hard, original color	Sound, hard, original color
2	Few limbs, no fine branches	Broken	Variable	Sloughing	Advanced decay, fibrous, firm to soft, light brown	Sound at base, incipient decay in outer edge of upper bole, hard, light to red brown
3	Limb stubs	Broken	Variable	Sloughing	Fibrous, soft, light to reddish brown	Incipient decay at base, advanced decay throughout upper bole, fibrous, hard to firm, reddish brown
4	Few or no stubs	Broken	Variable	Sloughing	Cubical, soft, reddish to dark brown	Advanced decay at base, sloughing from upper bole, fibrous to cubical, soft, dark reddish brown
5	None	Broken	Less than 20	Gone	Gone	Sloughing, cubical, soft, dark brown, OR fibrous, very soft, dark reddish brown, encased in hardened shell

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Annual Inventory 2007, Chapter 7: Live and Standing Dead Tree Tally

1 Characteristics are for Douglas-fir. Snags for other species may vary somewhat; use this table as a guide.

Figure 7-26: Douglas-fir decay class characteristics

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Coarse woody debris (Status =2, respond to prompts via D/L) is to be an ocular estimate with a record for each dead down log on a 1/24 acre fixed area plot. Coarse woody debris 8" or larger at the big end and 8 feet longer will be recorded.

Comments: Put all tree comments in the comment field in the tree data, or in the plot notes section of the data recorder. Please record comments as appropriate or necessary. Please provide management comments about fire effects and regeneration and site factors, etc.

Any conifer tree that forks (at the pith in the center) below DBH is tallied as a separate tree. If a tree forks above DBH record this information in the comments. Contrary to FIA specifications we do *not* want branches classified as individual trees as per FIA spec. The goal is a count of the actual number of trees and to accurately estimate carbon volume.

C. Photo. Take 5 digital photos at each plot center as explained above.

D. Site trees. These are recorded in the *.sit file. Measure the first qualifying bishop pine or Douglas-fir clockwise from north Dominant or Codominant with full crown (no breakage or broken tops please).

Methods: Reference the PNW FIA Plot Manual 2008 edition. All other field Data Collection Methods are described in the CARBON3.EXE tally program or in:

Part 3: Plot Coordinates

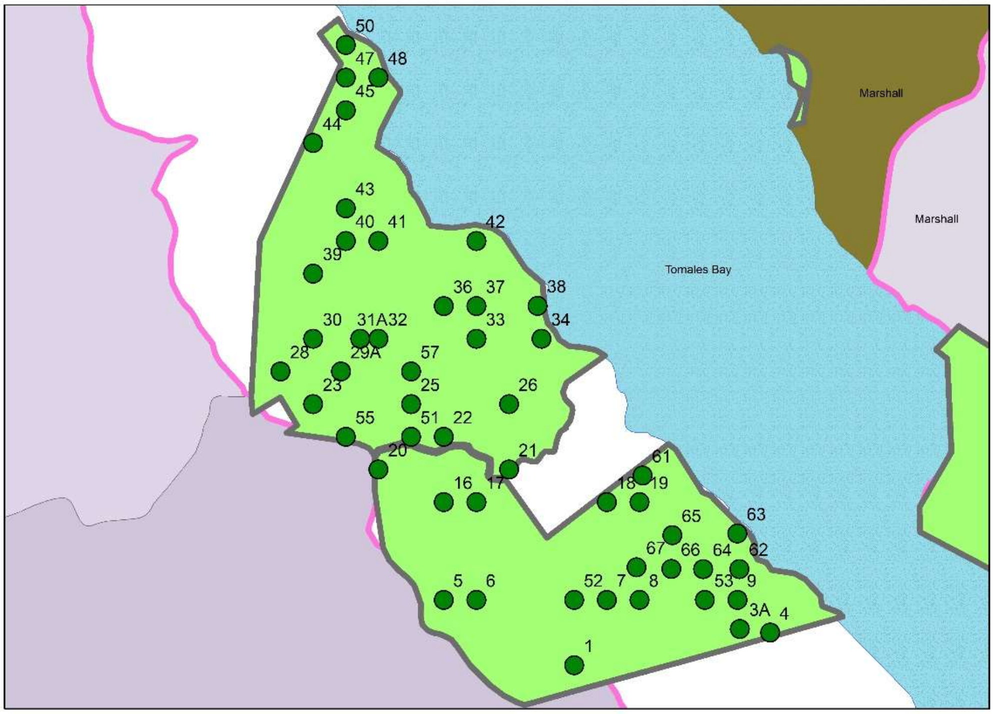
50 plots were selected for this inventory UTM Zone 10N, NAD83:

Plot	Plot	Latitude	Longitude	y_UTM	x_UTM
1	1	38.11255	-122.885	4218308	510063
3	3A	38.11419	-122.876	4218492	510904.5
4	4	38.11403	-122.874	4218474	511059
5	5	38.11555	-122.893	4218640	509399
6	6	38.11554	-122.891	4218640	509565
7	7	38.11554	-122.883	4218640	510229
8	8	38.11553	-122.881	4218640	510395
9	9	38.11553	-122.876	4218640	510893
16	16	38.12003	-122.893	4219138	509399
17	17	38.12003	-122.891	4219138	509565
18	18	38.12002	-122.883	4219138	510229
19	19	38.12002	-122.881	4219138	510395
20	20	38.12153	-122.897	4219304	509067
21	21	38.12153	-122.889	4219304	509731
22	22	38.12303	-122.893	4219470	509399
23	23	38.12453	-122.9	4219636	508735
25	25	38.12452	-122.895	4219636	509233
26	26	38.12452	-122.889	4219636	509731
28	28	38.12603	-122.902	4219802	508569
29	29A	38.12602	-122.899	4219802	508875.8
30	30	38.12752	-122.9	4219968	508735
31	31A	38.12752	-122.898	4219968	508974.4
32	32	38.12752	-122.897	4219968	509067
33	33	38.12751	-122.891	4219968	509565
34	34	38.12751	-122.887	4219968	509897
36	36	38.12901	-122.893	4220134	509399
37	37	38.12901	-122.891	4220134	509565
38	38	38.12902	-122.887	4220136	509876.1
39	39	38.13051	-122.9	4220300	508735
40	40	38.13201	-122.898	4220466	508901

41	41	38.13201	-122.897	4220466	509067
42	42	38.132	-122.891	4220466	509565
43	43	38.1335	-122.898	4220632	508901
44	44	38.1365	-122.9	4220964	508735
45	45	38.13799	-122.898	4221130	508901
47	47	38.13949	-122.898	4221296	508901
48	48	38.13949	-122.897	4221296	509067
50	50	38.14098	-122.898	4221462	508901
51	51	38.12303	-122.895	4219470	509233
52	52	38.11554	-122.885	4218640	510063
53	53	38.11553	-122.878	4218640	510727
55	55	38.12303	-122.898	4219470	508901
57	57	38.12602	-122.895	4219802	509233
61	61	38.12124	-122.881	4219273	510410.7
62	62	38.11695	-122.876	4218797	510903.1
63	63	38.11857	-122.876	4218978	510892.1
64	64	38.11694	-122.878	4218797	510718.8
65	65	38.1185	-122.88	4218969	510561.9
66	66	38.11695	-122.88	4218798	510557
67	67	38.11704	-122.882	4218807	510380.4

Part 4. Plot Locations

Tomales Bay State Park Forest Inventory Plots 2019



Part 5. The Data File

The resulting data set will look like the following and will be explained in the Project Design Documents::

```
     5  TG         12 26 2018  5    0
  05     1226A0                   12 26 2018      20   0   10  340   B5P 100 shrub= 90 grass=
5 littr= 40 duff = 30      small$=  3                  medium$=  1 large$=  1
PLT      SP    DBH    HT  LCR  STS  # PD                     DK  DK% COMMENT$
  05     120     8    12    0  WT2  1 4                      D 0  0  log
  05     120    20    41   50  WT0  1 3                      D 3  10  rough sound
  05     998    11    20   70  WT0  1 3                      D 0  0  myrica dbh below fork
  05     120    25    65   25  WT0  1 2                      D 0  0  pine gall canker
  05     120    28    65   20  WT0  1 2                      D 0  0
  05     120    32    53   10  WT0  1 2                      D 3  99  dying
  05     120    17    45   20  WT0  1 2                      D 0  0  shr is quva salal pomu1
  05     120    20    45   30  WT0  1 3                      D 3  30  rough not cull
  05     120    16    35    0  WT1  1 2                      D 0  30  5 pc gone
  05     120    32    32    0  WT1  1 3                      D 0  30  snag
  05     99
  06     1226A0                   12 26 2018      20   0   40   60   B5P 100 shrub= 99 grass=
0 littr= 30 duff = 50      small$= 12                  medium$=  0 large$=  0
  06     120    24    61   45  WT0  1 2                      D 0  0  line tree
  06     120    42    60   15  WT0  1 2                      D 0  0  pine gall rust cankers

      end
```

Part 6. Digital Attachments

Photos of all plots and historic aerial photography (imagery) are available at:

https://drive.google.com/drive/folders/10H0F1ujL-WfwzisYkFx32R580DRqTISV?usp=sharing

Inventory Plot data files and calculations worksheets (on request)

Geographic information Systems (GIS) shape files (on request)