Restoration of Oak Woodlands Impacted by Sudden Oak Death
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Introduction: Trees, stands, and forests are managed differently depending upon whether they are in the urban forest, the urban/wildland interface zone, recreational areas, or natural reserves. However, the overall process for evaluating tree and site resources and planning actions is similar across all of these settings. In these guidelines, our goal is to provide homeowners and resource managers a general framework that will allow them to make informed decisions about restoration in areas that have been impacted by Sudden Oak Death (SOD).

I. Planning and implementing restoration activities in SOD-affected areas

A. What do you have?
Evaluate the resource and determine how it has been impacted by Phytophthora ramorum and/or other agents of decline and mortality.

The presence of tree mortality related to SOD or other agents may or may not require specific management actions directed toward restoration of the forest or plant community. Therefore, the first step in dealing with the issue of restoration involves an assessment of what you have. Note that most existing stands have been heavily manipulated in the past, so that recent stand conditions, densities, species composition, and many other factors may be quite different from that which existed prior to settlement. Many stand characteristics will change over time in both managed and unmanaged stands. Although the impacts of SOD may appear to be immediate and short-term, restoration (either natural or assisted) will typically proceed over a period of at least several decades.

1. What changes have occurred in the stand?

a. Changes in stand density vs. changes in canopy cover
- Losses in tree density may not reduce overall canopy cover
- Replacement of trees lost from overly dense strands may not be feasible or desirable
- Changes in canopy cover are generally of greater use in determining impacts than changes in stand density

b. Have gaps been created and if so, what size?
- Regeneration in many coastal forest types is limited by the amount of light reaching seedlings and saplings
- Many tree species regenerate more successful in canopy gaps
-The size of the gap can influence which tree species are likely to dominate

c. Shifts in relative abundance of overstory and understory species
-Are dying trees locally common or uncommon relative to other species?
-Is composition or density of understory likely to be affected by tree loss? (related to gap size and species composition). If so, are changes likely to result in an increase of undesirable species, especially invasive exotics?

d. Loss of site-specific tree benefits
- Position of lost trees (relative to structures for shade, screening, other functions in urban landscape; erosion protection, streambank stabilization, etc.) affects the need for replanting and choice of species

e. Changes in amount of standing and downed dead wood.
- Changes in dead biomass may be relevant to safety concerns, wildlife habitat goals, etc.

- Very high levels of coarse woody debris could influence regeneration of some species
- Some regeneration could be at risk of damage from tree failures

2. What mortality factors are acting on the stand?

a. What are current and anticipated levels of mortality associated with* P. ramorum*?
- Current levels of infection may be used to estimate near term mortality due to SOD
- Currently asymptomatic trees may or may not be infected by *P. ramorum* in the future
- Not all trees with *P. ramorum* cankers will die within a few years, and some may survive indefinitely

b. What are current and anticipated levels of mortality associated with other agents?
- Changes in the stand due to other agents may be as or more important than *P. ramorum* in any given area
- Trees not at risk from *P. ramorum* may be at risk from other damaging agents

3. Assess the site for natural regeneration and capability for supporting various vegetation types.

a. Is advanced regeneration in the understory capable of being released through gap formation?
- Which species are present?
- What size classes are present?
- What are the densities?
- Are there seed sources for new seedlings?

b. Are invasive exotics (e.g., broom) present or likely to invade/dominate site?
- Which exotics are currently present?
- Are invasive exotics in adjacent lands?
- Are stand changes / disturbances likely to favor exotics?

c. Are site and/or management factors likely to constrain regeneration or establishment of various species?
- Climate, soils, slope, and aspect (water demand and availability) strongly influence success of various species
- Browsing by deer or livestock and damage caused by rodents can constrain regeneration
- Fire frequency and intensity can influence species composition
- Compaction and loss of surface litter associated with tree removal may adversely affect growing conditions for some species or may favor invasive plants
- Erosion potential and existing soil erosion may affect growing conditions
- In urban areas, irrigation and constraints posed by hardscape and utilities can influence which species can be grown

4. What is likely future disease pressure in area?
We currently lack epidemiological information to reliably predict future disease pressure. As more information becomes available. it may be possible to profile the relative disease risk of an area based on both the presence of foliar hosts and climate.

a. Are important foliar hosts of P. ramorum (e.g., California bay) present or abundant in the immediate area for local inoculum production?
b. What is the abundance/continuity of important foliar hosts in the general vicinity that

may serve as sources or airborne inoculum?
c. What is the likelihood of inoculum reintroduction associated with human activity?

B. What do you want?
Set or review tree or forest management goals in light of past, current, and projected resource condition.

Many landowners have not made a conscious effort to set goals for management of their tree or woodland resources. This "business as usual" approach to management may suffice if the current resource condition is acceptable and is not changing rapidly. However, if rapid changes in stand condition occur as the result of disease, the landowner is put in the position of either accepting changes that occur or attempting to change the outcome through various management actions. By setting goals that are consistent with the regional resource management goals and regulations, the uses of the property, and the landowner's needs and desires, the landowner will be able to make informed decisions about how to proceed in stands affected by *P. ramorum*.

1. What goals are compatible with current and potential future land uses and landowner's needs / desires?

a. Canopy cover goals
- What levels of canopy cover are necessary / desirable for:
- soil stabilization
- shading for energy conservation or plant /animal habitat
- visual screening
- aesthetics / property value enhancement
- suppression of undesirable invasive species
- management of fire and tree failure hazard around structures or other occupied areas
- maintenance or improvement of native plant and animal habitat / biodiversity

b. Species composition goals
- To what degree does stand composition / species selection affect goals?

2. What goals are consistent with regional land management goals and/or regulations that apply to the subject parcel?
- Trees and forests on both public and private lands provide a wide variety of public benefits, including soil stabilization, protection of water quality and aquatic habitats, stormwater runoff retention, interception of air pollutants, and conservation of native plant and animal species.
- The collective action of land management choices on many parcels can have regional impacts that affect the health and safety of people in communities and larger regions.
- Federal, state, and local laws, regulations, and guidelines exist to protect the public benefits provided by these resources. Typical regulations may limit grading, clearing, removal of certain native trees, destruction of wildlife habitat, and damage to riparian and wetland areas.
- Both habitat and individuals of endangered or threatened species are protected by state and federal laws.
- Regulations and guidelines related to fire hazard may influence the selection, placement, and management of plant materials and the management of dead vegetation.

3. Prioritize and resolve conflicts between goals.
- It may not be possible to fully achieve all goals that have been identified, and some may conflict with each other to varying degrees.

- The timelines associated with various goals may differ. Care should be taken to ensure that achievement of shorter-term goals will not interfere with attainment of high-priority longer-term goals.

C. How do you get what you want?
Evaluate management alternatives, select and implement management plans.

If the condition of the resource (what you have) does not correspond with the desired condition (what you want), then management actions such as planting or stand manipulations may be warranted. Often, landowners can use more than one approach to attain their management goals. By enumerating the possibilities and examining the pros and cons associated with each approach, the landowner can make an informed decision about how to proceed. Technical information about management alternatives needs to be considered in developing possible management scenarios (see Section II).

1. Identify alternative management scenarios that may satisfy most or all of the highest priority management goals.

- Can most or all goals be met by more than a single type of stand composition? For example, will various mixtures of tree species provide similar benefits?
- If no action is taken, how many goals can be met, i.e., is the no-action alternative viable?

2. What management actions are necessary to achieve goals in each alternative scenario?

- What inputs are required to implement each scenario?
- What risks or constraints are associated with each scenario? For example, would drought or extreme wet weather strongly influence success of a given plan?
- What is the long-term sustainability of the system under each scenario? How long would active management be required?

3. Identify costs and benefits associated with alternative management scenarios.

- High cost management alternatives may not provide the greatest benefit or highest likelihood of success (e.g., direct seeding or small liner stock may be more effective than higher cost large container stock)
- What resources are available to take management actions? Are grants or other sources of funding available?
- How will various alternatives fare if implementation resources are curtailed in the future?
- What are the positive and negative environmental impacts of various management scenarios?

4. Select and implement management alternative(s).

- A single alternative or a mosaic of alternatives may be appropriate.
- Implementation may be phased over a period of a few-to-many years. Risks associated with unfavorable weather (e.g., drought) may be minimized if the implementation schedule is flexible.

D. Are you getting what you want?
Evaluate success of management plan and adjust if needed.

Factors that influence the success of management efforts can vary widely across space and time, and many of these factors are beyond the control of the land manager. Outcomes for a given set of management inputs may vary by year, location, and species. Management of forests affected by SOD is clearly experimental because we lack the information needed to predict the outcome of various management methods. By keeping track of management inputs over time and carefully monitoring of the results of these inputs, one can more readily determine which inputs are the most effective and economical. This step takes the management process back to the question "What do you have?" In this step, we reevaluate the resource after management actions have been undertaken in order to see whether they have had their desired effects.

If seedlings vary genetically and we allow natural selection to function in the restoration process, high rates of seedling mortality can be expected in a successful restoration. If our primary restoration goal is to establish self-sustaining woodlands, selecting for adaptive characteristics is a higher priority than obtaining high rates of seedling survival. Excessive use of horticultural inputs, such as large nursery-grown stock and irrigation, may increase rates of seedling survival but allow seedlings with maladaptive traits to be recruited into the local breeding population, to the detriment of long-term stand sustainability.

1. Monitor survival and growth of regeneration.

- Survival and growth rates in natural regeneration or planted material may vary widely across a location or in different years.
- If several restoration methods have been used, a well-designed monitoring program will provide feedback on the efficacy of different methods.
- Short-term survival (first 1-to-5 years) may not be a good predictor of longer term survival (15-to-20+ years)

2. Monitor other stand factors related to regeneration

- Factors may include:
- gap filling by regeneration within the stand
- gap filling by expansion of existing tree canopies
- understory composition, including increases in invasive plant populations
- Stand factors may influence need for restoration and the outcome of restoration projects

3. Monitor disease and damage levels in remnant trees and regeneration

- Monitoring should include impacts of *P. ramorum* and other disease and damage agents
- Damaging agents may be important for only certain size classes and/or species

II. Technical considerations for restoration projects

Introduction: By following the process outlined in Section I above, a landowner may determine that some management actions will be required to attain goals that have been identified for the subject property. Some technical issues related to restoration activities in oak woodlands and other affected forests are presented in this section.

A. Urban versus wildland

Urban and wildland settings provide distinctly different sets of opportunities and constraints with respect to restoration. In general, more intensive inputs and attention to individual trees may be warranted in urban settings but are often impractical or unnecessary in wildland settings. Urbanized areas at the edge of wildlands (i.e., the urban/wildland interface) pose a more complex situation. While it may be possible to manage these areas as typical urban forests, tree management in this zone has the potential to significantly affect processes in the adjacent wildlands. Hence, people planning restoration activities in interface areas should consider the ecology of the surrounding forests in their planning.

B. Factors that constrain regeneration

Regeneration of oaks and other species may be constrained by a number of different factors. Restoration inputs are designed to overcome the specific constraints that are operating at a given site and time. The major factors that constrain regeneration of oaks and other woody species in SOD-affected forests are listed below. Notes under the topics in this section pertain primarily to oaks, but references to some other species are included.

1. Seed production
- Acorn production varies widely between individual trees and different years
- Oaks and other outcrossing wind pollinated species may not set seed reliably if remaining trees in the population are widely scattered

2. Seed or propagule dispersal
- Most acorn dispersal is by gravity, and most seed is deposited near parent tree
- Animals, especially jays, are involved in longer distance dispersal, but favor certain types of sites for depositing acorns, leading to nonuniform dispersal

3. Seedbed conditions
- Most acorns lose viability upon drying
- Lack of organic debris on the soil surface and soil compaction may greatly reduce acorn germination and seedling establishment

4. Damaging agents
a. Herbivores
- Livestock, deer, rodents, and insects can damage both acorns and seedlings
- Relative importance of different herbivores varies between land within locations
- Less palatable species are favored in areas where herbivory is high. Regeneration of preferred palatable species can be completely suppressed in areas with high herbivore pressure.
- Impact of herbivores can change over time with fluctuations in herbivore populations and amounts of alternative foods
- Herbivory impacts are greatest for small seedlings and saplings, especially those below the height of the browse line

b. Disease
- For some species (e.g., tanoak), *P. ramorum* has potential to reduce seedling growth and survival
- Endemic plant pathogens do not appear to have a major impact on oak regeneration in CA

5. Soil moisture
- Most oaks have at least moderate tolerance of low soil moisture, but can be killed by drought during the first few seasons of establishment
- Levels of soil moisture, especially minimum levels reached in late summer, limit which species may be able to occupy a site
- High plant densities increase competition for limited amounts of soil moisture
- Soil water holding capacity varies by soil type and soil organic matter content
- Organic debris on the soil surface helps conserve soil moisture
- Drought cycles or successive years of heavy precipitation may strongly influence plant establishment
- Shallow water tables or surface flows increase plant available water

6. Solar radiation
- Minimum amounts of light needed for seedling establishment and growth differ by species

- Tolerance of a species for low light may differ with age
- Evapotranspiration demand is reduced in shaded areas, and may compensate to some degree for limited soil moisture
- North-facing slopes receive the lowest amounts of solar radiation overall

7. Fire

- Species vary in their tolerance to fire and ability to resprout after topkill by fire
- Most California oaks resprout readily after fire, but repeated fires tend to eliminate oak regeneration
- Regeneration of some conifers and other woody species is highly dependent on periodic fires but oak regeneration is not fire-dependent
- Fire frequencies that permit regeneration vary by species
- For a given species, the fire frequency that permits regeneration varies by site
- Fires can greatly modify seedbed conditions by removing organic debris

C. Additional site constraints and hazards

Other factors that may need to be considered in planning a restoration project.

1. Tree failure

- Standing dead or heavily decayed trees may pose hazards to persons, property, or structures, especially in urban settings
- Individual tree evaluations are typically needed to assess failure potential and assess presence of targets that may be damaged if failure occurs
- Felling or failure of trees may put personnel at risk and destroy or damage natural regeneration or plantings.

2. Fire hazard

- Accumulation of dead plant material may increase fuel loads and may require attention prior to restoration efforts
- Potential fire hazard associated with new vegetation should be considered when selecting and locating new plant material, especially in urban areas

3. Soil erosion

- Soils may need to be stabilized to prevent erosion over the short term to allow establishment of slow-growing species
- Erosion occurring after tree removal may adversely affect site's ability to support vegetation that previously occupied the site
- Loss of surface soil reduces soil water holding capacity and available plant nutrients

D. Genetics of host species in restoration projects

1. Reasons for using locally-collected seed

- local genotypes are generally well-adapted to local soil and climate conditions, and are therefore likely to perform well.
- plantings from non-local seed may contaminate the local gene pool by introducing maladaptive traits into the local population. Through outcrossing with non-local individuals, specialized traits of local populations may be compromised or diluted.

2. Limitations of highly local seed

- a small local tree population may not have enough genetic diversity to include high levels of

resistance to SOD
- if site conditions have changed greatly since settlement, local germplasm may not be especially adapted to current site conditions. This may be especially so in areas where tree population is composed of sprout-origin (coppice) trees.
- local populations may already be genetically altered due to the presence of horticultural oaks or germplasm moved to the area by native Americans or subsequent settlers

3. Recommendations for managing genetic resources

a. Wildland and urban-wildland interface areas

- conserve local genetic resources where possible, especially existing seedling regeneration that has been exposed to selective pressures
- if planting is to occur, seed should be collected from a large number of individuals spread widely over the local seed zone. Because of variation in acorn production from year to year, seed collected in a series of years should be used where possible.
- avoid collecting acorns from trees likely to be pollinated by horticultural oaks of unknown provenance.
- woodlands within the same watershed and/or located within a few to perhaps 10 km of the restoration site may be considered as a local seed zone
- microclimate and soils of the source site should match the target site to the degree possible
- do not plant stock (nursery-grown or transplanted) of unknown or non-local provenance in areas where pollen and seed of planted trees may be spread into native stands (i.e., within about 3 km of existing stands).
- allow for attrition due to natural selective pressures: plant seeds or the smallest planting stock size available and plan for relatively high rates of seedling mortality

b. Urban areas away from existing natural stands:

- planting stock local to the region should be used in urban plantings away from existing stands
- use only plant materials from nurseries certified as free from *P. ramorum*

E. Matching restoration inputs to site constraints

Inputs needed to restore a site are based on an understanding of the site, including factors likely to constrain regeneration (II.B. above) as well as other site constraints (II.C. above). Although many of the factors may come into play at most sites, each location typically has a particular suite of issues that must be addressed in the restoration process. Restoration inputs that may need to be considered are noted below.

1. Mitigating fire hazard and failure potential associated with standing dead trees.

- standing dead trees are natural components of forests and woodlands and provide important wildlife habitat
- due to both cost and environmental considerations, removal or other treatment of standing dead trees should be limited to those where treatment is necessary based on management objectives

2. Conserving existing vegetation resources

- existing regeneration of desirable species may be present on the site in sufficient amounts to permit restocking of the site without planting
- equipment traffic, fire, or other site disturbances may adversely affect existing desirable vegetation

3. Managing competing vegetation

- competing vegetation may critically reduce both soil moisture and access of target plants to light
- shade produced by overstory species may be beneficial for initial seedling establishment for

most oaks and various other tree species
- suppressing or eliminating invasive exotic plants should be a high management priority, especially in sites where they have the potential to interfere with desired vegetation outcome
- management of native plant populations (e.g., excessive Douglas-fir regeneration) may be necessary in some sites to achieve desired stand composition
- operations should be designed and timed to minimize soil erosion and other negative consequences of management
- some species may be present and/or problematic only during certain successional stages of the restoration process
- use of fertilizers can increase problems associated with plant competition; soil fertility is not normally a limiting factor in oak regeneration

4. Protecting soils from erosion

- vegetative cover is critical for preventing soil erosion
- erosion potential also varies by soil type, slope, and rainfall characteristics
- tillage and other soil disturbance can greatly enhance soil erosion potential
- organic material on the soil surface, including dead and down woody material, may be important in reducing erosion
- intensive bioengineering (e.g., wattling) and/or mechanical (e.g., erosion control fabrics) inputs may be necessary to stabilize soils over the short term in specific sites

5. Plant protection

- protection against herbivores may be necessary in some sites in order to allow establishment or recruitment of desired species
- protection may be applied to individual plants (shelters, exclosures) or groups of plants (fencing)
- protective structures may modify plant form or have other non-target effects (e.g., increase in plant competition in areas where large herbivores are excluded)
- excessive use of plant protection may permit seedlings to become established that lack genetic characteristics (e.g., non-palatability) that are adaptive for early seedling survival

6. Conservation and augmentation of soil moisture

- organic mulch reduces evaporative loss of soil moisture and may be a cost-effective way to conserve soil moisture and suppress competing annual plants
- in some high-value situations, temporary irrigation may be used to offset seasonal drought and increase total available water
- irrigated seedlings may be more subject to attack by certain herbivores
- irrigation may permit seedlings to become established that lack genetic characteristics (e.g., root characteristics, drought tolerance) that are adaptive for early seedling survival

F. References and available resources

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