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Proposed Monitoring System for Adverse Biological Impacts Caused by the U.S. Forest Protocol

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1. Abstract

We recommended practical scientific methods for monitoring whether implementation of the Compliance Offset Protocol for U.S. Forest Projects (USFP) has biological effects that society may consider adverse. Monitoring methods were developed by a team of scientists with diverse expertise and informed by discussions with specialists on carbon sequestration in forests. We recommended linking all monitoring to clearly specified, measurable hypotheses about differences between management of USFP projects and management of similar forests that are not part of the USFP and the potential biological effects of those differences in management. We did not envision a plausible scenario in which implementation of the USFP would cause an adverse biological effect. However, we recognized that the Air Resources Board may wish to track data from USFP projects and other managed forests over time to test the well-supported hypothesis of no adverse biological effects.

2. Executive Summary

We examined potential biological effects of implementation of the Compliance Offset Protocol for U.S. Forest Projects (USFP) and recommended practical, scientifically rigorous methods for monitoring the occurrence of biological effects of the USFP that society may consider undesirable. Recommendations for monitoring were developed by a working group of eight individuals with diverse biological, analytical, organizational, and geographical expertise. Recommendations further were informed by structured interviews with experts on carbon sequestration in forests.

Through the working group meetings and interviews, we identified multiple theories of change and assessed their plausibility. A theory of change is a sequence of events—in this case, a series of management actions and resulting biological changes—hypothesized to occur in pursuit of a given objective. Neither the working group nor the experts we interviewed envisioned a plausible scenario in which the USFP would cause an adverse biological effect. Management actions intended to increase carbon stocks, such as actions that increase the standing biomass of trees (e.g., density of mature trees) or decrease the density of shrubs, might have biological effects that could be considered negative. However, it is not plausible that these actions would be more prevalent on USFP project areas than on other managed forests. We recognize that the California Air Resources Board (ARB) may wish to analyze data from USFP projects and other managed forests over time to verify whether the assumption of no unintentional biological effects is accurate. Accordingly, we recommend that ARB engage in a two-stage monitoring process.

We recommend that the first stage of monitoring document whether planned or ongoing actions described during listing or verification of USFP projects are consistent with the theories of change. If a given management action that is consistent with a theory of change occurs more frequently, with greater intensity, or over larger areas on USFP project areas than on similar managed forests in the same ecosystem, then we recommend considering a second stage of monitoring to assess biological effects of that action. Statistically rigorous matching of reference sites to USFP projects on the basis of physical, ecological, and social attributes and assessment of the counterfactual occurs during the second stage of monitoring. Implementation of the second stage of monitoring also would trigger determination by ARB of values of biological variables that would be judged adverse. It is necessary to define adverse quantitatively before analyzing data from stage two monitoring and drawing conclusions on the basis of those analyses.

The working group identified two theories of change at the level of USFP projects—increases in the density of mature trees and simplification of vegetation structure—that might serve as a foundation for stage one monitoring. However, neither the working group nor the experts we interviewed felt these theories of change were plausible. We also examined the possibility, raised during the public comment period, that clearcutting would be motivated by implementation of the USFP. Neither the working group nor the experts we consulted felt it was plausible that a USFP project could remain in compliance while increasing the amount of timber harvested within the project area's boundaries.

At the regional level, the working group felt it is possible that given the amenity value of open space, the listing of a considerable proportion of a region, such as an ecosystem or state, may drive development of low-density housing along the perimeters of USFP projects. At the program level, we considered the possibility that implementation of the USFP will lead to displacement of timber harvest from USFP projects to other areas, a phenomenon often referred to as *leakage*. Currently, however, there is no robust method of monitoring the occurrence and extent of leakage.

Monitoring unanticipated effects of the USFP requires definition of three terms: *biological effects*, *causation*, and *adverse*. We defined the first two terms. Biological effects refer to effects of implementation of the USFP on life at all levels of organization, from genes to ecosystems, and on biological structure, composition, and function. We considered biological effects that may occur at the level of USFP projects or at regional or program levels. Evaluating whether the magnitude of effects attributable to implementation of the USFP differ from those expected given a conservative, business-as-usual scenario of forest management requires assessment against a counterfactual: what would have happened if the USFP had not been implemented.

Adverse is a value judgment, and it was not appropriate for the working group to make such a judgment. We recommend that ARB engage social scientists, professional specialists on ethics, and natural scientists in a process of societal identification of values and translation of those values to quantitative thresholds of biological effects that will be considered adverse and may trigger adjustments of the USFP by ARB.

Availability of electronic data and metadata from the listing and verification process will facilitate reliable, efficient monitoring. Therefore, we recommend that ARB invest promptly in electronic maintenance of data and associated metadata. Substantial data will accrue from listing and verification processes and from additional monitoring of planned actions, realized actions, and biological effects of the actions. Metadata document the fundamental attributes of data, such as who collected the data, when and where the data were collected, what variables were measured, how and in what units measurements were taken, and the coordinate system used to identify locations. It is far more cost-effective to begin maintaining data and metadata at the outset of USFP implementation and to ensure all project data and metadata are captured electronically than to wait until data synthesis and analysis become urgent.

Well-maintained data and metadata will allow ARB or its partners to examine aggregated data at any point in time, whether to examine the current weight of evidence for a given theory of change, to compare biological responses to management actions on USFP projects and reference sites, or for any other reason. We recommend that ARB adopt metadata standards that are consistent with those of the National Spatial Data Infrastructure. Doing so will increase the transparency of the USFP and the complementarity of USFP data and other sources of data on carbon sequestration and forest management. We also recommend that ARB investigate the Data Documentation Initiative, an international standard for describing data from the social and behavioral sciences, as a standard for data that typically would not be characterized as biological or spatial.

3. Project Scope

As part of the rulemaking for the proposed Cap-and-Trade regulation, ARB prepared an environmental analysis that included the Functional Equivalent Document. On the basis of available data, and given regulations that constrain forest management, the environmental analysis concluded that the USFP is unlikely to have undesirable biological effects. However, ARB could not determine that such biological effects were impossible. Additionally, commenters raised concerns about the potential for negative effects on forest resources as a result of forest offset projects. Therefore, ARB committed to integrate adaptive management into implementation of the Cap-and-Trade program as a mechanism to address unanticipated and undesirable effects of the program.

On 20 October 2011, ARB approved an Adaptive Management Plan for the Cap-and-Trade regulation that included monitoring whether adverse biological effects resulted from implementation of the USFP. ARB then entered into a contract, The Forest Adaptive Management Contract (Agreement 11-426), with University of California, Davis to establish monitoring methods as required by the Adaptive Management Plan. Over 18 months, we examined potential biological effects of implementation of the USFP and recommended practical, scientifically rigorous methods for monitoring the occurrence of biological effects of the USFP that society may consider undesirable. As required by the contract, this report recommends a monitoring system for adverse biological effects caused by the USFP.

3.1. Project Approach

To develop robust monitoring recommendations, we first convened an expert panel (working group) of eight individuals that represented diverse biological, analytical, organizational, and geographical expertise. The working group convened in person three times to discuss and outline monitoring objectives and methods. Between meetings, the group interacted by telephone and email. One or more staff from ARB attended each meeting to answer questions about the USFP and the Adaptive Management Plan. Additionally, we were tasked with investigating whether existing data might be applicable to monitoring biological effects of implementing the USFP and whether collection of additional data would appreciably increase the amount or diversity of practical information that monitoring could provide.

To further explore potential biological effects of implementing the USFP, and to validate the inferences of the working group, we conducted structured interviews with verifiers, landowners, regulators, and staff of forest industries and environmental advocacy groups from multiple states.

Through working group meetings and interviews, we identified multiple theories of change and assessed their plausibility. A theory of change is a sequence of events—in this case, a series of management actions and resulting biological changes—that is hypothesized to occur in an effort to achieve a given objective. Although the working group and the experts we interviewed did not envision a plausible scenario in which the USFP would have biological effects that society might consider adverse, we recommended how ARB could track data from USFP projects and other managed forests over time to verify whether the assumption of no unintentional biological effects is accurate.

3.2. Key definitions

Recommending mechanisms to monitor unanticipated effects of the USFP required definition of three terms: *biological effects*, *causation*, and *adverse*.

3.2.1. Biological effects

We considered methods for monitoring biological effects of the USFP across the full range of biological diversity. Biological diversity is defined as life at all levels of organization, from genes to ecosystems, and encompasses structure, composition (species identity), and function. Common metrics of biological diversity include genetic variation within and among populations of species; the number of species in a given place and time (species richness); the number of individuals (abundance) in a population of a given species; distribution or evenness of abundances among species; structural complexity of vegetation or land cover; and spatial heterogeneity of land cover. Effects of a given natural or human-caused environmental change on a given element of biological diversity may be assessed either directly (e.g., by measuring whether recruitment of a given dragonfly population changes following a prescribed fire in a watershed it inhabits) or indirectly (e.g., by measuring whether stream sedimentation in the watershed is affected by the fire and then using those data to build a model of the effects of stream sedimentation on fecundity of the dragonfly population).

A direct measure of the response of a biological variable to a management action provides greater ability than an indirect measure to estimate the effect size (the magnitude of the change in a variable that one observes, or expects to observe, in response to a treatment or exposure to an agent of change). However, direct biological measures with high accuracy often are difficult to obtain (Niemi & McDonald 2004). In contrast, numerous well-accepted measures of the physical attributes of ecosystems (e.g., sedimentation or soil or water chemistry) are correlated with some biological responses in some ecosystems (Campbell & Doeg 1989; Davies & Nelson 1994; Dauer et al. 2000). We considered both biological and physical measures as valid indicators of biological effects when there was strong evidence that a measure of physical status was associated with biological status.

3.2.2. Causation

The literature on effects assessment and monitoring distinguishes cause and effect (causation) from associations that may not be causal (correlations) and emphasizes evaluation of causation. Our mandate was restricted to effects caused by implementation of the USFP; it was not to examine possible biological effects of forest management independent of the USFP. For example, an aggressive commercial timber-harvest plan may reduce cover of live trees and alter habitat for many species of animals and plants. A USFP project that includes timber harvest may have these effects. Our charge was to address whether the effects of implementing the USFP differ from those expected given likely management if the USFP did not exist.

Establishing whether implementation of the USFP has biological effects first requires a reasonable mechanistic hypothesis why some aspect of the USFP might be expected to have a given, measurable biological effect. In other words, establishing causation first requires a theory

of change. As a hypothetical example, imagine that a landowner wishes to optimize one recreational and two revenue-generating management objectives: off-road vehicle use, selective harvest of mature trees, and hunting. Coincident with listing of the area in a carbon sequestration program similar to the USFP, the landowner may add a third revenue-generating objective: the sale of credits from carbon sequestration. The landowner may perceive no negative effects of off-road vehicle use and issuance of hunting leases on accrual of carbon credits, and hence will continue these actions. However, if selective harvest reduces the ability to accrue carbon credits, then the landowner may adjust the level of selective harvest. In this case, any biological effects of hunting or off-road vehicle use are not attributable to the carbon sequestration program, whereas any biological effects of changes in selective harvest practices (which cannot be determined simply on the basis of data on volume of timber harvested) are.

Establishing causation then requires measuring actions and biological responses, and analyzing the resulting data statistically, to assess the weight of evidence for the hypothesis. Establishing causation further requires making identical measurements in other managed forests that are ecologically similar to USFP project areas. Statistical comparison of data from USFP project areas and similar locations is necessary to gauge what might have happened if the USFP had not been implemented. Economists and ecologists describe the latter process as assessment against a counterfactual: what would have happened if a given treatment, in this case the USFP, had not been implemented. Establishing an effect size or threshold for statistical significance requires definition of *adverse*.

3.2.3. *Adverse*

The Adaptive Management Plan requires ARB "to take a range of actions . . . to monitor and respond as appropriate to address unanticipated adverse impacts that are caused by the [cap-and-trade regulation] or the U.S. Forest Protocol." The concept of *adverse* is included in other environmental legislation in the United States. For example, the U.S. Marine Mammal Protection Act (16 USC 1361–1423) prohibits activities that will have an "unmitigable adverse impact" on subsistence uses "by any Indian, Aleut, or Eskimo who resides in Alaska and who dwells on the coast of the North Pacific Ocean or the Arctic Ocean." The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) requires the U.S. Environmental Protection Agency (EPA) to determine whether an application for licensing or registering a given pesticide will "perform its intended function without unreasonable adverse effects on the environment" [§ 136a (c)(5)(C)]. The FIFRA defines *unreasonable adverse effects on the environment* as any "unreasonable risk to man or the environment taking into account the economic, social, and environmental costs and benefits of the use of any pesticide" [§ 136 (z)(bb)(1)], and defines environment as "water, air, land, and all plants and man and other animals living therein and the interrelationships which exist among these" [§ 136 (j)]. In other words, the EPA has interpreted the "unreasonable adverse effects on the environment" standard to require assessment of trade-offs among effects of pesticide use on human health, the environment, economic trends, and social values (NRC 2013).

Notions similar to adverse, such as *significant effects* and *threatened*, also are central to the National Environmental Policy Act, California Environmental Quality Act (CEQA), and Endangered Species Act. Defining adverse is necessary because existence of an effect is not

sufficient to conclude that it is adverse (NRC 2013). Yet adverse and related terms are not defined quantitatively in the legislation, and there is no objective means for doing so. *Adverse* is a value judgment, and its definition requires one to make ethical judgments or express personal policy preferences (e.g., Wilhere 2012). These judgments invariably are rendered on a case by case basis, whether for different populations, species, processes, or activities. For example, the Natural Resources Agency's guidelines for implementation of CEQA recognize that "An ironclad definition of significant effect is not always possible because the significance of an activity may vary with the setting. For example, an activity which may not be significant in an urban area may be significant in a rural area." Guidelines for implementation of CEQA also note, "In determining whether an effect will be adverse or beneficial, the lead agency shall consider the views held by members of the public in all areas affected . . . ."

The ease of making value judgments to define *adverse* may vary among classes of biological effects. For example, if population growth rate is equal to or less than zero, the population will decline to extinction. Therefore, for species that society values, a population growth rate equal to or less than zero likely will be considered adverse. A National Research Council committee concluded that at the species level, the only reasonable way to determine whether an effect is adverse and how adverse it might be is to assess the degree to which it affects the species' survival and reproductive success in the wild (NRC 2013). Any effect that results in a change in survival or reproduction is relevant to the assessment, and any effect that does not change either outcome is irrelevant with respect to a quantitative assessment of population effects.

It is not uncommon for regulatory agencies to establish allowable thresholds, and these are analogous to definition of adverse. For example, the National Oceanic and Atmospheric Administration (NOAA) sets thresholds beyond which different types of sound-producing activities violate the Marine Protection Act. The NOAA currently considers root mean square sound pressure levels (rms SPL) $\geq$ 160 dB re 1μPa for intermittent sounds and $\geq$ 120 dB re 1μPa for continuous sounds as thresholds beyond which behavioral patterns of seals and whales may be disturbed and a rms SPL $\geq$ 180 dB re 1μPa as the threshold beyond which cetaceans may be injured physically. In this case, however, regulatory certainty does not reflect biological certainty. These sound thresholds are not supported by empirical data on individual-level or population-level effects of sound on physiology (Southall et al. 2007, Streever et al. 2012, Moretti et al. 2014). Static thresholds of injury or behavioral effects also do not consider biological realities such as differences in responses to sound of males and females, individuals of different ages, or animals that are caring for young versus migrating.

In the absence of a value judgment, monitoring cannot document whether effects are adverse. Monitoring can document facts, such as biological effects of various methods to increase carbon stocks. But goals are based on contemporary societal standards, and goals related to a given magnitude of effect should be determined prior to analysis. It is not best practice to measure environmental change and then decide whether the level of change is acceptable. If implementation of the USFP has biological effects at levels that society values as adverse, then ARB is expected to consider modifying the USFP as described in the Adaptive Management Plan.

Our working group did not believe it was appropriate for us to make the value judgments necessary to define adverse. Instead, we recommend that ARB engage social scientists, ethicists, and natural scientists in a process of societal identification of values and translation of those values to numeric thresholds of biological effects.

For example, although sedimentation is a natural process, sedimentation that is caused by timber harvest or road construction, maintenance, or traffic often is considered to have negative effects on ecological status. Detection of increased human action-caused sedimentation on multiple USFP project sites relative to reference sites might lead ARB to decide what level of sedimentation would trigger implementation of stage two monitoring and definition of adverse. By contrast, a decrease in abundance of a species or the area of its habitat may not uniformly be considered negative if, for example, the reduction in abundance was not associated with a decrease in population growth rate. Defining *adverse* also may be difficult with respect to biological attributes with highly variable historical or baseline values, such as fire frequency or tree density (Turner & Romme 1994; Tinker et al. 2003; Ravenscroft et al. 2010). In such cases, large effect sizes may be necessary to determine whether a threshold of change, let alone adverse change, has been reached. The fact that most ecosystems change over time (e.g., dominated by hardwoods versus conifers; early succession versus late succession) within a project area or ecosystem also presents challenges for defining adverse. We strongly recommend that before a second stage of monitoring is initiated, ARB engage in a process to define *adverse* for clearly identified response variables (see section 5).

3.3. Scales of potential effects

Biological effects of the USFP that may occur at project, regional, and program levels, and the methods for monitoring those effects, may be quite different. We define project-level effects as those that result from management actions within a given project area. A USFP project may be located anywhere in the continental United States, and species identities and abundances, carbon stocks, and typical management actions (e.g., managed fire) and their effects vary among ecosystems. Furthermore, many USFP projects have objectives in addition to carbon sequestration (e.g., preservation, recreation, resource extraction). Therefore, we recommend linking all USFP project-level monitoring to an explicit, quantitative theory of change. For example, if landowners aim to maximize carbon stocks in a naturally fire-dependent ecosystem, then they may suppress fire (a management action). As tree densities and successional stage increase, the probability of some major disturbances may increase (a biological effect).

As another example, USFP projects may be affected by regional fire-suppression policies. In these cases, managers may decide to harvest trees and shrubs as a substitute for fire, and there likely will be different professional or societal opinions about whether reducing the density of mature trees is biologically adverse or whether the reduction leads to adverse biological effects. We have not taken a position on whether thinning is positive or negative, but recommended monitoring to assess the extent of mechanical thinning on a USFP project and compare it to a counterfactual (what likely would have happened if the USFP had not been implemented). If the data on thinning from USFP project areas and reference sites suggest thinning is driven by implementation of the USFP, then it becomes the responsibility of ARB to determine the characteristics and magnitudes of change that would be considered adverse.

At the regional level, USFP projects may drive changes in land cover or the proportion of a given land-cover type that is relatively young or mature. For example, if large proportions of parcels with particular attributes (e.g., high productivity) are listed as USFP projects, certain land uses may be concentrated in less-productive areas; society may consider some biological effects of those land uses to be negative. Again, determining whether the USFP is driving such regional biological effects requires comparison to the counterfactual. In this example, it seems likely that the extent to which productivity drives land use would be the same whether management prioritized timber harvest or carbon sequestration, and, therefore, there would not be an adverse biological effect of implementing the USFP.

Effects at the program level are plausible. However, they are perhaps the most challenging to define and monitor because California is not the only current implementer of carbon trading programs and other programs likely will be adopted in the future. Therefore, it will be extremely difficult to distinguish programmatic effects that could be driven by multiple carbon trading programs. Potential effects would need to be measured on both USFP project areas and reference sites not enrolled in a carbon trading program.

Assessment of biological effects at either the regional or program level likely will require monitoring hundreds, if not thousands, of USFP projects. The number of enrolled projects and proposed types of actions might lead to theories of change that are not currently apparent.

4. Methods

4.1. Working group

The recommendations in this report largely were developed by a working group of eight individuals that represented diverse biological, analytical, organizational, and geographical expertise (Table 1). Two members were from California, one each from Oregon, Colorado, and Wisconsin, and three from Atlantic coastal states (Maine, New York, North Carolina). Group members also were distributed across types of organizations: one member from a university, two from federal agencies, and one each from a public museum, nonprofit forest consultancy, nonprofit conservation consultancy, and large nongovernmental conservation organization. Subject-area expertise ranged across different types of organisms (e.g., birds, butterflies, plants, mammals), disciplines (e.g., geography, forestry) and conceptual issues (decision making, monitoring, effects assessment, forest management).

The working group convened in person three times in Davis, California (18–19 October 2012, 31 January – 1 February 2013, and 15–16 May 2013) to discuss and outline monitoring objectives and methods. Between meetings, the group interacted by telephone and email.

Table 1. Participants in the USFP working group and attendance at each of the three in-person meetings.

	Affiliation	October 2012	January – February 2013	May 2013
Independent members				
Ned Horning	American Museum of Natural History	x[1]	x	x
Barry Noon	Colorado State University	x	x	x
Malcolm North	USDA Forest Service	x		
Kent Redford	Archipelago Consulting	x	x	x
Jon Remucal	Pacific Forest Trust	x	x	x
Dan Salzer	The Nature Conservancy	x	x	x
Kathryn Saterson	US Environmental Protection Agency	x	x	
John Wiens	PRBO Conservation Science		x	
Principal investigators				
Erica Fleishman	University of California, Davis	x	x	x
Mark Schwartz	University of California, Davis	x	x	x
Air Resources Board staff				
Barbara Bamberger	Air Resources Board			x
Jerry Hart	Air Resources Board		x	x
Shelby Livingston	Air Resources Board	x	x	

[1] Attended meeting

4.1.1. Summary of discussion during working group meeting 1

The working group recognized that defining *adverse* is primarily a societal responsibility that is informed by scientific assessment. Additionally, the criteria for determining whether a biological effect of the USFP is adverse must be established by ARB. The group agreed that the monitoring it recommended would focus on measuring the magnitude and direction of biological change on USFP projects relative to changes on comparable managed forests that are not listed as USFP projects. The group further agreed that its mandate was measurement of biological changes that might result from the USFP without characterizing those changes as positive or negative.

The working group discussed four of the many challenges to assessing biological effects of the USFP. The first challenge is that changes in structure, composition, and function on USFP projects may be driven by phenomena other than implementation of the USFP. Biological changes within project areas must be measured and interpreted relative to changes that likely would have occurred had the USFP not been implemented. That is, assessment of biological effects of the USFP requires comparison to a counterfactual.

The second challenge is that management to maximize carbon sequestration may increase the proportion of USFP projects, or the proportions of land within a USFP project boundary, that are in relatively late stages of succession. Mature forests often are highly valued because they may provide habitat for native species, including rare species that do not occupy younger forests.

However, mature forests also tend to have lower species richness than younger forests. Simply considering decreases in species richness in USFP projects as adverse likely would be misleading and counterproductive to societal desires to conserve native species. Thus, the group recommended that ARB recognize changes in structure, composition, and function of forests over time when establishing its criteria for *adverse*.

The third challenge is that the value attributed to a biological change depends on management objectives. For example, harvesting a patch of mature trees may be associated with a near-term increase in species richness of plants. The increase in species richness of plants may result from establishment of shade-intolerant native and non-native grasses and forbs (non-woody flowering plants that are not grasses). Whether those changes are considered positive, neutral, or adverse might depend on whether any species valued in the region are associated with early successional trees, whether the non-native species are designated as noxious, or how the changes compare with desired spatial configurations of land-cover types and ages across large areas.

The fourth challenge is that the USFP may have a biological effect if implementation leads to intensification of activities on lands that are not enrolled in the USFP. There was group consensus that changes in amenity values and associated fragmentation can be monitored in a fairly straightforward and reliable manner by comparing land prices or appraisals, land use, and land cover adjacent to USFP projects and reference sites.

There was group consensus that a potentially effective strategy for assessing the biological effects of the USFP is to develop and evaluate explicit theories about actions that may have particular biological effects. The group emphasized that any monitoring should collect data on state variables (e.g., percent composition of native species, distribution of age or stage classes, structural complexity, abundance of coarse woody debris, snag density) on USFP projects and on reference sites where a given management action is hypothesized to have a given biological effect. Values of state variables would be compared through time (e.g., every two to five or more years, depending on the speed at which values of the variable typically change) to estimate responses to management and associated effect sizes. These effect sizes would be compared to a previously established definition of adverse.

Multiple estimators allow one to match USFP and non-USFP sites with respect to, for example, vegetation, topography, disturbance processes, ownership, and governance (Abadie & Imbens 2006; Ho et al. 2007; Nolte & Agrawal 2013). The full set of matched USFP project sites and reference sites allows for determining the probability that changes are associated with the treatment rather than site-specific attributes (Ferraro 2009, 2011). Environmental changes such as establishment of non-native invasive species, changes in fire regimes, or changes in climate at regional to global levels may occur simultaneously with USFP implementation. Human activities such as timber harvest also may be ongoing in both USFP project sites and matched non-USFP sites. Additionally, attributes of the enrolled sites, or motivations for enrolling sites, might confound measurement of biological effects of the USFP (Ferraro 2009).

There was group consensus that development of a uniform monitoring method to assess biological effects of the USFP is not feasible. Actions hypothesized to cause adverse biological effects, and associated response variables and covariates (independent variables), will vary

among USFP projects. Additionally, existing national-level monitoring programs generally are insufficient with respect to response variables and covariates, spatial distribution or resolution, or temporal resolution to detect biological changes and draw conclusions about causation across a majority of USFP projects and reference sites.

The group noted that previous attempts to monitor a comprehensive set of ecological variables were terminated by their respective organizations (e.g., the U.S. Environmental Protection Agency's Environmental Monitoring & Assessment Program [EMAP] and State of the Environment reports and the Heinz Center's State of the Nation's Ecosystems). Among the reasons for termination were the expense of collecting data and the inadequacy of the data for assessing ecological status and trends. The group underscored that extensive, standardized monitoring of the biological effects of the USFP would require a substantial investment of funds yet have limited power to detect change. The group discussed methods for detection of biological change and the applicability of existing sources of data to detecting biological effects of the USFP (see section 5).

4.1.2. Summary of discussion during working group meeting 2

During its second meeting, the working group agreed that monitoring biological response variables, then determining whether changes in values of those variables are attributable to the USFP, would not be scientifically robust or efficient. Instead, a robust and efficient method is to identify actions attributable to the USFP and then determine whether those actions have biological effects that society might consider adverse. Thus, the group concentrated on establishing plausible theories of biological change that may result from actions motivated by the USFP. The group agreed to use these theories of change as a basis for its monitoring recommendations.

The working group subsequently discussed a process that assesses biological effects of the USFP at two levels. The first level would document what actions are planned and conducted on USFP projects with the objective of evaluating whether actions generally are consistent with achieving ecological management objectives. For instance, the objectives of minimizing colonization by non-native invasive plant species and maintaining diverse composition and structure of native plant species typically are achieved by management actions that will be identified in materials required of USFP projects and reference sites. The group proposed synthesizing information on actions currently conducted under the Climate Action Reserve's Forest Project Protocol and comparing them to common business-as-usual forest management practices. Monitoring would focus on whether management actions that were not anticipated by ARB could have potentially undesirable biological effects.

The second level would target long-term biological effects of the USFP. Three classes of effects were hypothesized. First, substantial changes in the price of carbon or timber could change behaviors of landowners. Thus, monitoring might track whether proposed actions change as market prices change. Second, land uses associated with implementation of the USFP could have cumulative biological effects at the regional level. Third, changes in climate may change the distribution of species and thus land-cover types; forest may not have a high probability of occurring on all USFP project sites, or species composition may differ from that specified in the

USFP's current descriptions of ecosystems. The group proposed long-term monitoring of the degree to which climate change drives changes in management actions.

4.1.3. Summary of discussion during working group meeting 3

The working group discussed in detail actions mandated or prohibited by the USFP, allowable actions that are common in business-as-usual forest management, and potential biological effects of the USFP that may occur over relatively long periods of time and large areas. The group considered whether plausible theories of change might coincide with biological effects of prohibiting or implementing given actions. For example, improved forest management projects allow removal of brush and short-lived trees that compete with long-lived trees. Reducing the structural complexity of vegetation may have undesirable ecological effects, but the group felt that the probability of brush-clearing, especially as a direct result of listing as a USFP project, was low.

By the end of the May 2013 meeting, a consensus emerged from the working group that generic, spatially extensive monitoring would have a high probability of failing to meet ARB's objectives. Coarse-filter monitoring often uses remotely sensed information to compare general patterns of vegetation change in treated sites and reference sites. There are two reasons why using only these methods likely would not meet ARB's objectives. First, the lag time from implementation of monitoring to generation of results would be long given the slow rates of change in many forest ecosystems. Second, it would be nearly impossible to determine whether specific attributes of the USFP drove the changes.

At fine resolution, methods exist for monitoring physical variables (e.g., sediment loads) and biological variables (e.g., species richness and density of birds). Both physical and biological attributes are highly variable even when management actions are consistent. Therefore, unless a monitoring program was linked to an explicit theory of change (e.g., carbon stocks will be increased by mechanical removal of shrubs via actions that are not applied beyond USFP projects, and these actions will reduce species richness and density of birds that nest in shrubs), we expect that one would document considerable variation in the response variables that could not be explained easily. Again, selection of response variables and covariates requires a plausible theory of change.

Given this consensus, rather than attempting to develop a generic monitoring program, we recommend a two-stage monitoring program that is explicitly adaptive. We recommend that the first stage focus on management actions that are implemented on USFP projects and, in some cases, other managed forests in the same ecosystem. If the data suggest management actions are consistent with one or more theories of change, then we recommend initiating a second stage of monitoring that measures, in the field or remotely, whether hypothesized biological changes are associated with the actions. Matching of reference sites to USFP projects on the basis of physical, ecological, and social attributes and assessment of the counterfactual occurs during the second stage of monitoring. Implementation of the second stage of monitoring also would trigger determination by ARB of values of biological variables that would be judged adverse. Ultimately, if quantitative analysis suggests biological effects of implementation of the USFP

meet an explicit, previously determined definition of adverse, then the USFP itself may need to be revised.

4.2. Structured interviews

4.2.1. Interview preparation

The working group recommended that its collective experience and understanding of biological responses to carbon sequestration in forests be augmented by that of additional experts. Our aim was to elicit the experts' knowledge or professional opinions about management actions that might be motivated directly by the USFP and potential negative biological effects of those actions.

Experts were suggested by participants in the working group and by ARB program managers. Some of the experts offered suggestions for others whose experience might inform development of the monitoring program. We made an effort to speak with individuals who are affiliated with multiple types of organizations.

We contacted each expert by email to explain the objectives of the USFP and of our work. If an expert agreed to speak with us, we sent the expert a synopsis of the USFP (Appendix A). During our telephone conversation, we asked each expert about her or his professional experience with forest carbon sequestration programs, including the USFP; management actions either within or beyond USFP projects that might warrant tracking; and potential negative biological effects of actions driven by implementation of the USFP (Appendix B). We asked each expert to react to two illustrative theories of change outlined by the working group. We also asked an open-ended question about implementation and potential biological effects of the USFP.

4.2.2. Interview results

We spoke with 24 experts. Eight were affiliated with non-profit organizations, four with government agencies, 11 with for-profit organizations that conduct carbon-sequestration verification, and three with academic institutions. The later total is greater than 24 because some individuals had more than one affiliation. Collectively, the individuals with whom we spoke had expertise in forest and carbon sequestration research, development and implementation of carbon-storage projects, and project verification and auditing.

None of the experts with whom we spoke foresaw clear negative biological effects of implementing the USFP. Nine thought it was possible that the USFP would create an incentive for increasing the density of large trees (i.e., creating more standing biomass than would be expected given natural vegetation succession) or other vegetation to the point that probability of fire might increase. However, other experts felt landowners would be aware of relations between increases in fuel loads and probability of fire and therefore would not substantially increase the standing biomass of trees and other vegetation. One expert suggested that the USFP could create an incentive to harvest timber. Five noted that projects may increase habitat quality for some species, especially those that occur in relatively mature forest or woodland, and decrease habitat quality for other species, especially those that occur in early successional woodlands. One

mentioned that the USFP might limit landowners' ability to eradicate or minimize the expansion of non-native invasive species. Similarly, one expert felt that if management of USFP projects was more passive than management of other forests, then landowners would spend less time inspecting their property and might overlook the early stages of colonization by non-native invasive species.

One expert mentioned that verification criteria for forests in the northern United States might not capture the full range of species diversity. One questioned whether creation of easements might limit future management options.

Experts suggested monitoring whether the following management actions are planned or implemented on USFP projects and similar managed forests.

- Understory clearing, which can reduce habitat quality for some species

- For reforestation and improved forest management projects, actions after a disturbance. The choice of species that are replanted may affect habitat quality for some species, resilience of the ecosystem to natural disturbances, and primary productivity.

- Actions in riparian zones, which could affect the extent of erosion and habitat quality for some species

- Salvage logging, which could affect habitat quality for some species that occupy relatively mature forests

- Removal of downed wood. This action could affect habitat quality for some species, extent of erosion, and rates and quantities of nutrient cycling.

Experts also suggested monitoring the following biological or legal elements of USFP projects and similar managed forests.

- Shrub cover, which affects habitat quality for some species

- Density of trees or standing biomass, which could affect water availability and probability of fire

- Composition and density of woody plant species that grow relatively quickly (e.g., early successional species), which could affect habitat quality for some species of animals and herbaceous plants

- Mean age of trees in a given stand, which could affect probability of fire or outbreaks of pests

- Number of easements, which could affect future options for management

We asked 18 of 24 experts whether the UFSP could create an incentive to clear land, refrain from replanting for 10 years, and then enroll as a reforestation project. One expert felt creation of such an incentive was possible depending how the baseline was defined. Many experts commented that because landowners receive no credit until carbon accumulates, and because timber currently has a higher value than carbon, such a scenario was unlikely. There are additional regulatory and practical reasons why such a scenario is unlikely (section 7.2.3).

5. Monitoring Biological Effects

We recommend that ARB engage in a two-stage monitoring process. Whether theories of change seem plausible or implausible, we recommend that the first stage of monitoring document whether planned or ongoing actions described in the course of listing or subsequent verification of USFP projects are consistent with the theories of change.

During the first stage, we recommend monitoring response variables, primarily actions, that can be measured on the basis of readily available information from verifiers or reliable public or private sources. For example, as detailed in section 7.2.1, it was hypothesized—albeit with low plausibility—that the objective of obtaining carbon credits might encourage management for uncharacteristically high density of mature trees, which might increase the probability of disturbances such as fire, disease, and outbreaks of insect pests. Plausibility of the theory of change was considered low because landowners generally recognize the relation between woody biomass and disturbance, and stand loss would reduce carbon credits.

If the first stage of monitoring indicates that management actions are consistent with a theory of change, then we recommend initiating a second stage of monitoring to measure, in the field or remotely, whether hypothesized biological changes are associated with the actions. Any difference between USFP projects and similar managed forests with respect to actions associated with a theory of change might trigger stage two monitoring. Matching of reference sites and assessment of the counterfactual would occur during the second stage. Implementation of the second stage of monitoring also would trigger a determination of values of biological variables that would be judged adverse. Quantitative definition of adverse effectively specifies an effect size, which makes it possible to calculate the number and attributes of USFP projects and paired reference sites necessary to estimate whether that threshold is reached.

5.1. Measuring biological responses to management actions

Natural and human-caused environmental changes directly or indirectly affect all levels of biological diversity. Entities or processes that reduce probabilities of individual survival or population viability, or decrease ecological function, within a given location and time period often are referred to as *stressors.* Stressors are important to recognize and address because they do not exist as independent phenomena but relative to response variables or state variables. For example, a ship is not a stressor. Depending on the biology and behavior of a marine mammal, the sound created by the ship, effluent from the ship, or the possibility of a ship strike may function as a stressor. Determining whether a given management action creates one or more stressors, assessing the effects of any one stressor, or assessing the aggregated or cumulative effects of multiple stressors requires one to identify response variables and to specify the spatial

and temporal boundaries of the assessment. We define aggregated effects as net effects of concurrent stressors and cumulative effects as net effects of all stressors over a given period of time. To draw strong inference one must monitor the stressor, the response variable, and environmental covariates (e.g., elevation, precipitation) that reasonably might be expected to affect the relation between the stressor and the response.

Theories of change lead to identification of biological response variables and stressors. Once an action driven by the USFP is identified, one can estimate whether potential stressors might be created by the action. For example, timber harvest might require maintenance of an access road via operation of vehicles, vegetation removal, and soil manipulation. The same action may not function as a stressor to all biological elements within a given geographic and temporal window or, for example, to both sexes or all life stages of a given species. Sound from operation of vehicles may function as a stressor to a bird that is establishing a breeding territory, whereas the potential for collision with vehicles may function as a stressor to a small mammal. The species itself is not a response or state variable; its probability of occupancy or population growth rate is a response or state variable. It is essential to identify mechanisms by which a known or hypothesized stressor may affect response variables. That is, it is not sufficient to simply assert that sound might reduce population viability. Instead, there must be a credible hypothesis that, for example, the level of sound from operations will mask bird songs to the extent that male birds cannot attract mates.

Noon (2002) suggested that candidate response variables for monitoring be sensitive to changes in values of the stressor, have a short-term but persistent response to changes in values of the stressor, be amenable to accurate and precise estimation, and have low or well-understood natural variability. Noon (2002) also recommended that the probability of detecting a change in values of the response variable be high given a change in values of the stressor and that changes in values of the response variable are readily differentiated from background variation. These criteria reinforce that a direct measure of biological response to a management action has greater information content than an indirect measure. It is far more difficult to monitor changes in the probability of occupancy of Pinyon Jay (*Gymnorhinus cyanocephalus*) and to assess whether those changes were driven by trends in the density of singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) trees than to measure changes in tree density. The closer the relation between management action and response variable, the greater the probability of credibly evaluating the action's biological effects.

The literature on effects assessment rarely addresses the level or threshold at which effects become biologically meaningful (Schultz 2010). Regulatory thresholds may exist, such as an absolute level of sound received by a marine mammal or the population size of an endangered species. However, these thresholds typically are not based on data that reliably link the level of human action to the level of biological effect (section 3.2.3.). Although any threshold ultimately is a value judgment (Wilhere 2012), quantitative thresholds allow one to estimate sample sizes necessary to assess whether the threshold has been reached at a given effect size.

Specification of response variables increases the ability to effectively regulate human actions because the same actions may have different biological effects at different spatial and temporal scales. To illustrate, probability of ignition and severity of fire typically vary as a function of

fuel moisture during different seasons. Hence, open fires and use of camp stoves on national forests in the arid west typically are restricted during summer, but not during winter.

5.2. General data sources

Sources of data discussed in this section were identified in the original contract proposal and are addressed in fulfillment of our contractual obligation. Our recommendations for use of a given source of data in stage one or stage two monitoring are predicated on their relevance to a plausible theory of change for which evidence could be assessed by comparing data from USFP projects and reference sites. In most cases, it is impossible to categorically recommend whether a given source be used to monitor biological effects of the USFP. The applicability of these sources to monitoring depends on the locations of USFP projects, their dominant land cover types, spatial and temporal extent and resolution, and the theory of change being assessed. There was group consensus that development of a uniform monitoring method to assess biological effects of the USFP is not feasible. Actions hypothesized to cause adverse biological effects, and associated response variables and covariates (independent variables), will vary among USFP projects.

Assessment of the biological effects of the USFP during stage two monitoring will require measuring biological structure, composition, and function within USFP projects and reference sites. Compliance criteria for species composition, diversity, and age distribution of trees are mandated by the natural forest management provisions of the USFP. However, verification data may not be sufficient to assess whether individual or aggregated USFP projects support habitat for native plant and animal species or whether biological changes reliably can be attributed to implementation of the USFP. Here, we examine the extent to which existing sources of data on land cover and species occurrence (Table 2) may be applicable to the second stage of monitoring. For detailed, easily understood information on application of remote sensing to biological or ecological assessment, we recommend Horning et al. (2010).

Biological changes at the level of USFP projects may be measured over time, compared to changes in other locations, or both. Some studies examine change in biological attributes within one or a relatively small number of sites over time, often during a period of natural or human-caused environmental change. Numerous sampling designs, such as Before-After Control-Impact (BACI), are applicable to moderate- to long-term studies. However, long-term studies are not designed to distinguish among changes associated with the treatment versus external factors (e.g., climate change, atmospheric deposition of nutrients, regional expansion of non-native invasive plants). By contrast, comparative studies focus on assessing biological change in sites that are similar except for the treatment of interest. Site matching allows one to gauge whether differences between treated and non-treated sites are associated with the treatment rather than site-specific attributes. Ideally, methods for change detection will be both long-term and comparative. It is likely that many non-treated sites that are potential matches to USFP projects will be privately owned. Therefore, whether biological effects of the USFP can be assessed rigorously may depend in part on whether ARB is able to obtain access to private lands.

Table 2. Potential applicability of existing sources of data to the recommended first and second stages of monitoring biological effects of the USFP. Recommendations are predicated on relevance of the data to a plausible theory of change for which evidence could be assessed by comparing data on actions and biological effects of those actions from USFP projects and comparable reference sites.

Data type	**Data source**	**Recommended for stage one monitoring**	**Recommended for stage two monitoring**
Land cover (conterminous United States)	Gap Analysis Program (GAP)	Yes, where applicable	Yes, where applicable
Land cover (conterminous United States)	Landscape Fire and Resource Management Planning Tools (LANDFIRE) program	Yes, where applicable	Yes, where applicable
Land cover (conterminous United States)	National Land Cover Dataset (NLCD)	Yes, where applicable	Yes, where applicable
Land cover (conterminous United States)	National Agricultural Statistics Service	Yes, where applicable	Yes, where applicable
Land cover (state level)	California Forest and Range Assessment Program	Yes, where applicable	Yes, where applicable
Restricted land cover	National Wetlands Inventory	No	No
Restricted land cover	Global Observation Research Initiative in Alpine Environments (GLORIA)	No	No
Raw satellite imagery	Advanced very high resolution radiometer (AVHRR)	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Moderate resolution imaging spectroradiometer (MODIS)	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Satellite pour l'observation de la terre (SPOT)	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Landsat	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Advanced spaceborne thermal emission and reflection radiometer (ASTER)	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Ikonos	Yes, where applicable	Yes, where applicable
Raw satellite imagery	Quickbird	Yes, where applicable	Yes, where applicable
Raw satellite imagery	GeoEye	Yes, where applicable	Yes, where applicable
Field measures of plants and soils	Forest Inventory and Analysis (FIA) program	No	No
Presence of breeding birds	North American Breeding Bird Survey (BBS)	No	No
Presence of non-	Invasive Plant Council of California	No	No

native invasive species	(and equivalent programs in other states)		
Risk of loss of carbon stocks on USFP projects	Forest buffer accounts	Yes, where applicable	No
Annual greenhouse gas emissions	End users via Mandatory Reporting Regulation	No	No
Timber harvest in California	California Department of Forestry and Fire Protection (CalFire) in compliance with California Forest Practices Act	No	No
Timber harvest in California	California Department of Forestry and Fire Protection (CalFire)	No	No
Taxable value of harvested timber in California	California Board of Equalization	No	No
Condition of forests and areas used as rangelands in California	California Department of Forestry and Fire Protection (CalFire) via Fire and Resource Assessment Program	No	No
Tax filing status of landowners	Internal Revenue Service	Yes, where applicable	Yes, where applicable

5.2.1. Land cover and composition of plants

Land cover is the biological or physical cover on Earth's surface. It encompasses both natural features, such as dominant vegetation, rock, and water, and features created by humans, such as agricultural fields and urban areas. Land use is the social or economic activity associated with a given type of land cover. In some cases, land cover and land use may be synonymous. However, additional information often is necessary to differentiate land cover (e.g., grassland) and land use (e.g., livestock grazing), especially when a land cover class is associated with multiple land uses.

National initiatives such as the Gap Analysis Program (GAP), Landscape Fire and Resource Management Planning Tools (LANDFIRE) project, National Land Cover Dataset (NLCD; a product of the U.S. Geological Survey's Land Cover Institute), and National Agricultural Statistics Service (which produces the Cropland Data Layer; http://nassgeodata.gmu.edu/CropScape/) provide free digital maps of land cover for most of the United States.

Some state programs, such as the California Forest and Range Assessment Program, also provide free digital maps of land cover. In most cases these classifications are derived from Landsat images and therefore have a spatial resolution of 30 m. The frequency of updates varies among initiatives, from one year to five or more years. Whether existing classifications are sufficient for stage two monitoring or whether it will be necessary to produce a custom classification will depend on whether hypothesized changes in land cover class and resolution are consistent with the existing classification. For example, presence and abundance of some non-native invasive

grasses in the understory is not documented by existing classifications. We recommend using the existing classifications where sufficient.

A few national programs, such as the National Wetlands Inventory and Global Observation Research Initiative in Alpine Environments (GLORIA) Program, provide data associated with particular land-cover or ecosystem types. However, vegetation types likely to be represented in USFP projects generally are not the focus of these programs. Therefore, we do not recommend use of data from these programs.

Land cover usually is characterized on the basis of remotely sensed data. Satellite images and aerial photographs are acquired by both public and private sources. There are trade-offs among the spatial extent, spatial resolution, spectral resolution, and temporal resolution of remotely sensed images or data. As spatial extent increases, spatial resolution typically decreases. For example, images from the advanced very high resolution radiometer (AVHRR) capture widths on the ground of 2600 km and have a spatial resolution (cell sizes) of 1.1 km, those from the moderate resolution imaging spectroradiometer (MODIS; modis.gsfc.nasa.gov/) capture widths on the ground of 2330 km and have a spatial resolution of 250–1000 m, and those from the satellite pour l'observation de la terre (SPOT) have a swath width of 60 km and a spatial resolution of 2.5–20 m.

As spatial resolution becomes finer and spectral resolution increases, the feasibility of detecting individual species, such as non-native invasive plants, generally increases. Ability to monitor phenology and rapidly detect changes in land cover increases as the frequency of acquisition increases. Imagery with high temporal resolution tends to be spatially extensive but has large cells and few spectral bands. The data are reliable, but whether they are applicable to stage one or stage two monitoring depends on the theory of change, ecosystem, and spatial and temporal extent and resolution at which measurements are necessary. We recommend using the data when applicable.

There also are trade-offs among resolution and cost of satellite data. For example, images from AVHRR, MODIS, Landsat (Thematic Mapper [TM], Enhanced Thematic Mapper Plus [ETM+], and the new Operational Land Imager [on Landsat 8]), and the advanced spaceborne thermal emission and reflection radiometer (ASTER) are free. High-resolution images such as Ikonos, Quickbird, and GeoEye cost about $10–20 per square kilometer. Additionally, the latter images often are acquired only when tasked—that is, unlike images from MODIS or Landsat, they are not acquired on a regular schedule. Again, whether the data are applicable to stage one or two monitoring depends on the particular hypothesis, location, and resolution. We recommend using the data when applicable.

Land cover classifications usually are based on associations between spectral signatures, plant growth forms such as trees or shrubs, and plant associations that are common in different biogeographic regions. For example, photosynthetic and non-photosynthetic vegetation have different spectral signatures. Seasonal phenology also may facilitate differentiation of land-cover classes. Detection of individual species on the basis of remotely sensed images is relatively rare. The target species must have a spectra, texture (shape or growth form or pattern),

or phenological signal that is different from the surrounding species, and its percent cover must be high at the spatial resolution of the image.

The USDA Forest Service's Forest Inventory and Analysis (FIA) program was established in 1928. The sample units, plots, are about 1 hectare and are located on the basis of a random stratified design. Where possible, the plots are approximately 2390 ha apart. Sampling methods have become much more systematic over the past 20 years, increasing the extent to which data from FIA plots can be compared across space and time. However, because the density of FIA plots across the United States is relatively low, few USFP projects are likely to encompass one FIA plot, let alone multiple plots. The resampling interval for a given plot is about five to seven years. The locations of plots and sampling data are not publicly available, and obtaining permissions is time-consuming. Therefore, we do not recommend application of data from the FIA program to stage one or two monitoring.

5.2.2. Vegetation structure and function

Land cover classifications generally provide little information on structural complexity of vegetation. Radar measures energy returned (essentially the inverse of absorbed) by objects on the ground and allows one to estimate the structure of vegetation beneath the canopy. Radar-based methods are promising, but too expensive and experimental to be feasible for second-stage monitoring at present. Light detection and ranging (lidar) measures the lag time between transmission and receipt of light and provides direct measures of vegetation structure. Some publicly available lidar data have been compiled by the U.S. Geological Survey through various contracts, partnerships, and purchases (lta.cr.usgs.gov/LIDAR); many lidar systems are commercial. For a given application, and especially for assessments of land-cover and land-use change, obtaining and processing data can be costly. Additionally, because lidar images often are captured for a specific purpose in a relatively small area, it may be necessary to combine data from multiple sources and points in time if one wishes to examine lidar data for a relatively large area. Combining data from multiple sources can be time-consuming and technically challenging, and the combined data may be less reliable than data that were obtained at the same time.

Common measures of ecological function in forests are photosynthetic activity and biomass. Photosynthetic activity often is measured with vegetation indexes, ratios of near-infrared to visible red wavelengths (photosynthetic vegetation has high reflectance in the near-infrared). The most common is the Normalized Difference Vegetation Index (NDVI): (near infrared – visible) / (near infrared + visible). The NDVI measures greenness, which typically is correlated with photosynthetic activity and biomass. When biomass is quite high, NDVI and other vegetation indexes change little as biomass increases further and become less effective for estimating changes in productivity. The enhanced vegetation index (EVI) is similar to NDVI but corrects for attributes of the atmosphere and vegetation canopy that obscure parts of the satellite image. The EVI generally is more effective than NDVI when vegetation is dense. Multiple gridded values of NDVI and EVI (e.g., maximum, mean) derived from MODIS data are available at no cost from the National Aeronautics and Space Administration (NASA) at multiple spatial resolutions (250 m, 1 km, 0.05˚) and temporal resolutions (16-day, monthly).

Measures of ecological function also include the fraction of photosynthetically active radiation (FPAR; wavelengths of 0.4 – 0.7 nm) that the forest canopy absorbs and leaf area index (LAI), which represents the proportion of radiation converted to biomass. Values of FPAR, LAI, and net primary production (calculated on the basis of land cover, FPAR, LAI, and meteorology) are available as MODIS products with resolutions of 1 km. We recommend using these data when applicable to a given theory of change.

5.2.3. Assemblages and species

Changes in phenology often are detectable long before changes in species composition or abundance. Organizations such as the USA National Phenology Network synthesize data on numerous taxonomic groups from diverse organizations and individuals. In some cases, remotely sensed data allow assessment of project-level phenological changes in vegetation (Schwartz 1994; Schwartz et al. 2006; Cleland et al. 2007). There is a strong phenological signal of climate change in some forests in the United States.

Remote identification of non-native invasive plants is an active area of research. Most studies identify non-native invasive plants on the basis of spectral differences between the target species and the surrounding vegetation. Differences in plant pigmentation, water content, or leaf chemistry result in spectral differences. Multispectral differences are most likely to be detected where the target species is dominant in the canopy. Invasive plants that have distinctly colored flowers, such as leafy spurge (*Euphorbia esula*) and perennial pepperweed (*Lepidium latifolium*), may be feasible to detect on the basis of hyperspectral satellite images or color aerial photographs. Use of remote sensing to identify non-native species on the basis of their flowers only is possible when the flowers of the invasive species can be differentiated from those of native, co-occurring species, and the invasive species generally must be at the top of the vegetation canopy.

It may be possible to remotely identify an invasive species on the basis of phenology if it has a different seasonal or annual growth pattern than native species—for example, if it becomes green earlier, stays green longer, or its growth is more responsive to changes in temperature or precipitation. This method typically requires a time series of images, such as those from Landsat, MODIS, or AVHRR. Phenological mapping of invasive plants also requires that cover or density be high relative to pixel size. The method per se is reliable, but currently can be used to detect initial colonization by a small proportion of the many non-native species of relevance to forest management. We recommend using the method, but recognize that its current application is limited.

Numerous methods exist to sample major taxonomic groups of animals (e.g., insects, mammals, and birds) in forests. Inferences from sampling of insects such as ants or butterflies can be highly uncertain because species in some families are difficult to identify and their distributions are quite variable in time and space; these attributes make it extremely difficult to associate changes in species composition and distributions with natural or human-driven environmental change. Surveys of mammals and birds typically are somewhat more reliable and repeatable, but it still can be quite difficult to attribute observed changes to management actions. We do not recommend monitoring animals.

Species richness generally is a weak measure of biological status. Although counting species is relatively easy compared with estimating other response variables, there is little evidence that species richness by itself provides insights to ecosystem properties. Inferences to ecosystem properties require information on both species' functional effects on ecological properties and species' functional responses to natural and anthropogenic environmental change (Hooper et al. 2005). Species richness per se provides no information on density or demography of individual species and thus provides no insights to probabilities of species persistence (the inverse of extinction). Consistent relations between species richness and area or values of environmental variables, such as elevation or precipitation, cannot be assumed, especially within taxonomic groups with short generation times or ecosystems with considerable variation in daily, seasonal, and annual weather. We do not recommend monitoring species richness.

The working group did not identify a national networks of animal-sampling sites to which data from USFP projects might be compared. For example, the North American Breeding Bird Survey (BBS) is a transnational program coordinated by the U.S. Geological Survey's Patuxent Wildlife Research Center and the Canadian Wildlife Service's National Wildlife Research Center. Data are collected by skilled volunteer observers. The monitoring program is well established, and analyses of the survey data have been included in more than 450 publications. Numerous studies have examined the information content of BBS data (Boulinier et al. 1998; Royle & Nichols 2003; Sauer et al. 1994) and whether reliable inference about associations of birds with different locations and land cover types can be drawn from the data (Davey et al. 2012; Hartway & Mills 2012; Veech et al. 2012). Multiple points, typically along roads, are sampled once during the breeding season. One sample does not allow estimation of whether species were absent or undetected, and many species breeding in the vicinity may not be detected during the sampling period. Therefore, we do not recommend using data from the Breeding Bird Survey to assess biological effects of the USFP.

Many natural disturbances and human activities increase probabilities of colonization and establishment of non-native invasive species. These species may affect ecosystem function or persistence of native species. Most states have an organization that tracks non-native invasive species (e.g., Invasive Plant Council of California, www.iscc.ca.gov/), but data collection is not necessarily systematic and often is not sufficient to build models of occupancy or population dynamics. Project-level monitoring programs often measure the degree to which the site supports non-native invasive plants and animals. Research may be necessary to determine whether site management practices are likely to affect presence, abundance or dominance, or persistence of non-native invasive species. We recommend monitoring non-native invasive species, but only when consistent with a systematic, rigorous sampling design.

6. Forest Management Data

Data are collected as a function of listing and verification of USFP projects. Here, we examine the extent to which data from sources identified by ARB in our scope of work can be applied to the first and second stages of monitoring (Table 2). We recommend that all data collected directly by ARB or obtained by ARB from other sources—regardless of whether addressed below—and associated metadata be archived electronically (section 8) promptly upon collection. We recognize that some of the data on management actions that are acquired by verifiers or

public resources agencies, or reported to public resources agencies, are proprietary and therefore are not publicly available.

6.1. USFP project data

Diverse data will be acquired by ARB or approved verifiers from USFP projects. These include fundamental site attributes (e.g., location, assessment area, type of project, ownership, reporting period) that can be used as candidate covariates for the first stage of monitoring (section 5). An additional variable that we recommend recording is tax filing status of the landowner. We recommend aggregating tax filing status into six general classes: individuals, for-profit organizations (e.g., corporations), private operating foundations (e.g., family trusts), social welfare organizations (e.g., conservation nongovernmental organizations), Tribes, and governmental units (e.g., a city, county, or regional management district) or quasi-governmental entities (e.g., public utilities). We also recommend recording whether all or part of the USFP project is included in a conservation easement. Data on tax filing status is not required for verification, but can be derived from documentation of Project Operators' ownership interest, which is required during the application process. We believe that tax filing status may be a useful variable for matching reference sites and associated with management actions. If monitoring includes collection of data on tax filing status, then management actions can be screened to gauge whether they differ on forests enrolled in the USFP and on other managed forests. Such information is a prerequisite for any stage two monitoring.

Data obtained through the USFP documentation process that can be used to classify projects on which actions appear to support a theory of change and to match sites for assessment of the counterfactual include

1. Date of USFP project listing
2. Whether any part of the project area has been included in another offset program (e.g., Climate Action Reserve)
3. Whether there is a timber harvest plan for the project
4. Project boundaries and governance jurisdictions (e.g., state, counties, towns)
5. How management will meet the definition of Natural Forest Management, including species composition, distribution of age classes, and assessment of standing and lying dead wood
6. Ecosystems within the project area
7. Reversal risk rating and contribution to the Forest Buffer Account

6.2. Forest buffer account information

Forest buffer accounts will address carbon losses through unintentional reversals. USFP projects are required to calculate a reversal risk rating that specifies the contribution to the forest carbon buffer account. Risk is associated with variables such as financial failure, illegal biomass removal, conversion, levels of harvest that lead to net carbon loss, or catastrophic losses driven by wildfire, disease, insects, or other phenomena. It is unclear whether these data may contribute to monitoring of biological effects. If risk does not vary geographically, then landowners and verifiers may not feel that data on the variables are relevant to risk estimates. It also may be

plausible that risk estimates are not a focus of listing and verification and may be systematically underestimated or overestimated, whether by assessment area (or other environmental gradients) or at the program level. The USFP recognizes that timber values may drive landowners to absorb the financial loss of a forest carbon reversal and harvest relatively high volumes of timber. Although doing so might have undesirable biological effects, those effects would not be caused by implementation of the USFP. If timber prices increased, harvest volumes or rates likely would increase independent of the USFP. The cost of a reversal on a USFP project would reduce the likelihood of intensive harvesting relative to that on unlisted areas. We recommend auditing the risk rating of USFP projects to evaluate the variability in risk and to verify that risk rating is accurate.

6.3. Mandatory reporting of greenhouse gas emissions

Mandatory reporting of annual greenhouse gas emissions by major sources is required by AB 32. The reporting includes use of forest-derived wood and wood waste for biomass fuels. We considered whether data on use of biomass fuels compiled through the Mandatory Reporting Regulation might be used to evaluate human behaviors with respect to biomass production on USFP projects and similar managed forests. Biomass may be removed through removal of understory shrubs and trees, selective harvest or thinning of trees, or more-intensive timber harvest. However, the Mandatory Reporting Regulation does not appear to require that the landowner or verifier report the form of biomass removed for energy. Instead, reporting is the responsibility of the end user of the biomass for energy production. If the end user is not the landowner, then information from the Mandatory Reporting Regulation likely has limited value for monitoring because biomass cannot be linked to a specific land parcel. If the end user is the landowner, then data on biomass removal represent an independent source of information on understory removal, thinning, and harvest. Comparable data collected in the field or on the basis of remotely sensed imagery from unlisted areas could facilitate comparison of biomass removal. Biomass removals cannot be linked with certainty to USFP projects or other areas, and it is likely that different errors are associated with estimation of biomass removal via mandatory reporting versus field measurement. Given these limitations, we do not recommend incorporating the data into stage one or two monitoring.

6.4. Inventory of greenhouse gas emissions in California

The ARB is working with University of California, Berkeley to develop a greenhouse gas inventory system for forests across California. The system will integrate data from the FIA program, Natural Resources Conservation Service (NRCS), LANDFIRE program, and MODIS enhanced vegetation index (EVI) to generate spatially and temporally explicit estimates of carbon stocks over time and attribute changes in carbon stocks to processes or land uses such as fire, resource extraction, and land-cover conversion. The effort will estimate fluxes of carbon dioxide, methane, and nitrous oxide on the basis of changes in carbon stocks.

It is unlikely that this system could contribute to evaluating theories of change because it is limited to California. Additionally, no theory of change associated levels of carbon dioxide, methane, and nitrous oxide with biological effects caused by implementation of the USFP. Assessment of evidence for the theories of change may reference variables measured in a

greenhouse gas inventory (e.g., greenness or biomass). However, variables such as greenness or biomass would be more useful as direct measures of forest productivity than as potential measures of biological effects. We do not recommend incorporating the greenhouse gas emissions data into stage one or two monitoring.

6.5. California Forest Practices Act

Data collected by the California Department of Forestry and Fire Protection (CalFire) in compliance with the California Forest Practices Act, a functional equivalent to the California Environmental Quality Act for timber harvest, are restricted to California. Therefore, their applicability to stage one monitoring is geographically limited. It is quite difficult to assess whether information from the California Forest Practices Act process would facilitate assessment of theories of change within California. The apparent purpose of these data is to ensure that the undesirable biological effects of forest management within California are mitigated. The laws, including mitigation requirements, are applicable regardless of whether a given area is included within a USFP project. This is another fact that led the working group and experts to agree that there is no plausible theory of change that the USFP could cause adverse biological effects. It is possible that the magnitude of biological effects on USFP projects and reference sites could be compared via information collected to comply with the California Forest Practices Act. All of our theories of change, however, suggest that reductions in timber harvest rates and intensity of management actions driven by carbon sequestration will decrease the probability of biological effects on USFP projects. Hence, we do not recommend recording data from California Forest Practices Act compliance documents.

6.6. Timber yield tax and harvest values schedules

The California Board of Equalization establishes the taxable value of harvested timber. Data on timber harvest value are aggregated by county. Data are associated with individual properties, but the data are proprietary and ARB would not be able to access the data unless it extended its information-sharing agreement with the Board of Equalization. If the data become available, then they might be used to assess the degree of timber harvest on USFP projects versus other managed forests, with tax filing status of the owner as a covariate.

One could compare the timber harvest value reported by USFP projects to the taxable value of timber harvested elsewhere within the same county. However, estimates of timber harvest on USFP projects and other managed forests compiled by this method are likely to have high uncertainty unless management objectives and tax filing status or management jurisdiction are similar throughout the county. We do not recommend aggregating yield tax data as a primary source of information on harvest attributes of biological interest or using these data for stage one or two monitoring.

Two other methods of comparing timber harvest on USFP projects and other managed forests are possible. First, remotely sensed data can be used to assess the size of harvested patches (see section 5). Second, data on harvest and tax filing status could be collected from landowners. The former method is feasible, but the latter method does not seem feasible given owners of

unlisted areas may not wish to provide these data. We do not recommend using data on timber harvest value for stage one or two monitoring.

6.7. Fire and Resource Assessment Program

The Fire and Resource Assessment Program (FRAP), implemented by CalFire, periodically assesses the condition of forests and of grasslands used for livestock grazing. The FRAP identifies priority areas for action under the State Wildlife Action Plan (http://www.dfg.ca.gov/swap/). However, FRAP does not collect primary data. We do not envision any response variables that could be inferred from the FRAP data and used to assess evidence for theories of change or to monitor biological effects of the USFP at the project level. We do not recommend use of FRAP data to assess biological effects of the USFP.

6.8. CalFire Forest Practice GIS

CalFire's Forest Practice geographic information system (GIS) captures current and historic timber harvest on over 4 million acres (about 16,200 km^2) of California's approximately 25 million acres (about 100,000 km^2) of forest. The working group and experts we interviewed hypothesized that timber harvest volume and frequency would be lower on USFP projects than on other managed forests. To assess support for this hypothesis, one could compare the timber harvest plans of USFP projects (which, unlike those for other private lands, are available) to observed timber harvest across these 4 million acres over the past decade. This comparison would estimate the magnitude of the difference between business-as-usual timber harvest with that expected on USFP projects. The estimate is likely to have high uncertainty because attributes of USFP and other managed forests that may affect volume and frequency of timber harvest (e.g., productivity, elevation, species composition, slope, ruggedness) are not matched. However, timber harvest on sites with similar values of these covariates could be compared.

CalFire's data also include new road construction within forests. We assume the majority of new road construction within forests is intended to facilitate forest management. These data can be used to compare recent business-as-usual road construction to that on USFP projects. We expect that listing as a USFP project will reduce road construction (section 7.2.4). However, if data indicate otherwise, then road construction on USFP projects and other managed forests can be monitored over time with data from CalFire and other publicly available sources.

7. Recommendations for Monitoring Biological Effects of the USFP

7.1. Data collection and analysis

Consistent with the Adaptive Management Plan, we recommend that ARB collect and analyze data to assess whether the theories of change described below are realized. The information already required to determine eligibility and for verification, along with remotely sensed or field data from sources such as the U.S. Geological Survey and state wildlife agencies, is sufficient to evaluate most of these theories of change.

7.2. USFP project-level theories of change

Through working group meetings and interviews, we identified theories of change and assessed their plausibility. We identified theories of change at the level of USFP projects, regions, and the program, and we identified the mechanisms by which management actions might be associated with biological changes (effects) that society might consider adverse. However, neither the working group nor the experts we interviewed felt that the theories of change were highly plausible. That is, the working group and experts did not envision a plausible scenario in which the USFP would cause an adverse biological effect. The working group and experts recognized that the USFP itself is fairly restrictive. USFP projects must be occupied by multiple native species and managed to achieve ecological objectives. These ecological objectives include a mandated level of coarse woody debris, which restricts salvage logging. In addition, carbon accounting requires discounting for timber harvested, even if this carbon is retained in permanent wood products. We determined that it would be exceedingly expensive and inefficient to monitor biological response variables that are highly unlikely to be affected by listing of a USFP project.

Despite the fact that the working group and experts did not envision a plausible theory of change, we recognize ARB may wish to track data from USFP projects and other managed forests over time to verify whether the assumption of no unintentional biological effects is accurate. If so, then we recommend monitoring three measures of timber harvest (length of rotations, size of clearcuts, volume of wood harvested) and construction of roads in association with timber harvest (Table 3). Again, we find it implausible that the USFP will increase the occurrence or frequency of timber harvest. The USFP contains provisions to reduce harvest volume and lengthen rotation times, and limits the size of clearcuts. Given that some landowners will not harvest timber, road construction also is likely to decrease relative to business-as-usual. Nevertheless, at least in California, these four variables are easily measured through data already required as conditions of listing and verification (see section 6.1).

7.2.1. Increases in carbon stocks via increases in density of mature trees

The first theory of change at the level of USFP projects is that in an effort to increase carbon stocks, landowners, particularly in the arid west, will act to increase densities of mature trees on USFP projects relative to what would be expected in the absence of the USFP. Increases in the density of mature trees may increase the probability of wildfire, tree disease, and tree-pest outbreaks. This theory was not viewed as highly plausible by the working group and outside experts because it increases the landowner's risk of losing carbon. Nevertheless, plausibility was regarded as higher for avoided conversion and improved forest management projects than for reforestation projects. Whether increases in tree density are a direct result of USFP implementation is difficult to assess because landowners whose primary source of income is harvesting trees but are not participants in the USFP have the same incentive to increase tree densities as landowners of USFP projects: increase standing biomass while not increasing the probability of catastrophic losses to fire, disease, or pests.

If ARB wishes to monitor whether implementation of the USFP leads to increases in tree density, then we recommend assessing the prevalence and frequency of actions that reduce tree density,

such as thinning and managed fire. The extent of actions intended to reduce tree density may not be apparent until after five to ten years of active management, and we hypothesized that such actions may be more common on USFP projects in arid biomes west of the 100th meridian than in biomes east of the 100th meridian. Measures of tree density (i.e., direct effects of the actions) likely can be based in part on remotely sensed data. For example, the NDVI or LAI may be correlated with tree density, especially at the peak of the growing season in non-drought years. Reliable measures of fire are available from public agencies at no charge. For example, wildfire perimeter and severity across the western United States are mapped by the National Interagency Fire Center. The MODIS burned area product (MCD45A) identifies burned area and date, and the Monitoring Trends in Burn Severity (MTBS) program provides 30-m data, derived from Landsat, on the severity and perimeters of fires > 404 ha.

Until it becomes clear whether stage two monitoring, including selection of reference sites, is warranted, we recommend comparing tree density on USFP projects and on an equal area of forest in the same ecosystem, located at random, where evidence suggests that probability of fire, disease, or pests is reduced by reducing tree density. With respect to this theory of change, demonstrating a negative biological effect of the USFP would require evidence that management actions on USFP projects differ from those on similar areas not enrolled in the USFP, that these actions are associated with increases in the density of mature trees, and that increases in standing biomass are associated with increased prevalence, frequency, or severity of disturbance in many forest ecosystems. The ARB then would be responsible for determining whether the magnitude of the change in disturbance met a societal definition of adverse and warranted modification of the USFP.

7.2.2. Simplification of vegetation structure to increase carbon stocks

The second theory of change is that the objective of increasing carbon stocks will lead to actions that decrease understory cover to a greater extent than other management objectives. The working group and experts were skeptical that reducing understory cover would be economically feasible. Nevertheless, sufficiently high carbon prices might create incentives for mechanical or chemical shrub removal. The biological effects of shrub removal may be less in California than in moist hardwood forests in the eastern United States, where a diverse understory of shrubs and subcanopy trees may inhibit regeneration of canopy trees.

During stage one, we recommend monitoring both the actions included in management plans and realized actions to assess the extent, intensity, and frequency of shrub removal on USFP projects and on randomly selected areas in the same ecosystem. In some locations, it may be possible to estimate shrub cover over time via lidar data. However, in other locations, use of lidar data to monitor shrub cover may not be feasible (see section 5.2.2).

Landowners who are not participating in the USFP are not obligated to report management actions. Therefore, if the magnitude of shrub removal is considered sufficient to implement stage two monitoring, it may be most feasible to examine the potential for establishing reference sites on lands that are owned by individuals who have listed USFP projects.

7.2.3. Increased clearcutting

Neither the working group nor the experts we interviewed felt it was plausible that a USFP project could remain in compliance while increasing the amount of timber harvested. The USFP is designed to account for carbon removed from project areas and requires that carbon stocks within project areas increase. As a consequence, we anticipate logging intervals will become longer, reducing the volume of timber extracted from improved forest management projects. Moreover, the USFP requires landowners to maintain mean canopy cover ≥ 40% across all of their forests in the same ecosystems covered by the Project Area, which will minimize the potential size of clearcuts. States such as California have additional restrictions on the size of clearcuts allowed, and legislation in any state that restricts logging to a greater extent than the USFP would take precedence.

We recommend examining data on timber harvest plans and realized timber harvest collected via the USFP listing and verification process. Remotely sensed data likely would be sufficient for stage one monitoring. Publicly available information is sufficient to assess the association of the USFP with clearcutting in California.

Members of the working group, interview group, and public questioned whether implementation of the USFP might lead to an increase in clearcutting on lands not enrolled in the USFP (leakage). However, given the available information, a reliable way to accurately assess the extent of leakage—as distinct from simply the locations where trees are harvested—is not apparent.

It is possible, but quite unlikely, that landowners could remove trees, refrain from planting or prevent recruitment for 10 years, and then enroll as a reforestation project. Such a series of actions is especially unlikely in states in which timber harvest, and in some cases replanting after harvest, is highly regulated. The ARB chose ten years as the minimum period a location must have had less than 10% tree canopy cover to be eligible as a reforestation project. Given the large transaction costs of establishing a USFP project, it is unlikely that many sites will qualify as reforestation projects. Our discussions with experts suggested that given current carbon prices, the likelihood that a landowner would cut a sufficiently large area and prevent natural reforestation for 10 years in order to enroll with a low carbon baseline is quite low. Additionally, verifiers felt such actions were not intended by the USFP and that they would be reticent to associate themselves with such a project. Nevertheless, it is relatively simple to assess whether reforestation project listing increases substantially in 2023, ten years after implementation of the USFP. Additionally, we recommend tracking carbon prices to determine whether there is an association among timing of the most recent timber harvest, listing of reforestation projects, and carbon prices.

7.2.4. Increased road construction

Although there likely is little motivation to construct roads for purposes other than access to harvestable timber, road construction can be interpreted from high-resolution (30 m or finer) remotely sensed images. We recommend compiling data on road construction on USFP projects and other managed forests in the same ecosystems during stage one monitoring.

7.3. Region-level theories of change

Evaluating region-level theories of change is substantively different from evaluating theories of change at the level of USFP projects. In some cases, evaluation of regional theories of change associated with extensive patterns of land use may be based on remote sensing data.

We did not set a threshold for the proportion of a given ecosystem that should included within USFP projects to initiate consideration of region-level theories of change. However, metapopulation theory (Hanski 1999) and some landscape ecologists (Andren 1994; Fahrig 1998; With & Crist 1995) suggested that when habitat loss or fragmentation results in a 70–85% loss in the area of a species' habitat, the probability that a population will be lost increases appreciably. Theoretical thresholds of habitat quantity and configuration are species-specific (e.g., Monkkonen & Reunanen 1999). Operationally, it would be ideal if one could identify a threshold level of listing above which USFP projects may affect the ecology of an ecosystem, but the research in landscape ecology and related disciplines does not provide tangible evidence of such a threshold. Although this recommendation is subjective, we recommend not studying the cumulative effects of the USFP until at least 15% of an ecosystem has been listed.

7.3.1. Increased proportion of late-successional forest

The working group hypothesized that if the USFP and other carbon sequestration programs become regionally popular, then implementation of these programs may increase the regional proportion of late-successional forests. The biological effects of an increase in the proportion of late-successional forests likely would not be considered negative either in disturbance-dependent ecosystems or in regions where disturbance is relatively rare (e.g., northeastern hardwood forests). An increase in late-successional forests in the western United States in the near future seems unlikely because the frequency and extent of disturbances such as fire, insects, and diseases are increasing throughout that region. Nevertheless, it would be feasible to monitor whether the proportion of late-successional forests increases and some biological effects of that increase. Thus, if USFP projects represent a substantial proportion of an ecosystem that is occupied by species restricted to early successional forests, an increase in the proportion of late successional forests might be considered undesirable. In that case, remotely sensed data might be used to assess whether the proportion of late successional forests is increasing.

At the regional or program level, the USFP theoretically could lead to loss of habitat for some protected species. As an example, Kirtland's Warbler (*Setophaga kirtlandii*), a species listed as endangered under the U.S. Endangered Species Act, is restricted to young jack pine (*Pinus banksiana*) forests in Wisconsin and upper Michigan (Probst & Weinrich 1993). Jack pine is a fire dependent, early successional species. Hypothetically, if a large proportion of this region was listed as USFP projects, and if the landowners managed to maximize the number or density of mature trees, then the amount or quality of habitat for Kirtland's Warbler would decrease. Management of habitat for Kirtland's Warbler, such as the maintenance of young jack pine stands, may be regulated by the Endangered Species Act. Historically, however, it has been difficult to use the Endangered Species Act to regulate the cumulative effects of natural processes, such as forest maturation, on habitat; natural processes are not regarded as human actions that lead to take. Extensive studies of Kirtland's Warbler have led to intensive

management of the age of jack pine stands, and the species is unlikely to be affected by the USFP. Nevertheless, this case suggests a possible focus of program-level monitoring.

Substantial biological effects caused by dramatic increases in the proportion of late-successional forest, however, are unlikely to be driven by the USFP for at least three reasons. First, late successional forests historically were the dominant land cover over much of the eastern United States. Hence, the USFP would not have a dramatic effect unless listing encompassed a considerable proportion of the eastern United States. Second, fire is common across much of the forested western United States and contributes to maintenance of forests in early to intermediate successional states. It seems unlikely that the USFP would substantively alter the successional status of extensive ecosystems. Third, the eastern United States is dominated by small parcels and the western United States by federal lands. Accordingly, it seems unlikely that either eastern or western forests could be dominated by USFP projects. We recommend that stage one monitoring at the regional level include measurement of the area and proportion of each ecosystem that is included within listed projects. We recommend that ARB consider further monitoring of the proportions of successional stages if listing encompasses a substantial proportion of a given ecosystem.

7.3.2. Increased urbanization

The working group felt it is possible that given the amenity value of open space, considerable regional listing may drive low-density housing development along the perimeters of USFP projects (Quigley & Swoboda 2007). Housing development in the wildland-urban interface, which is recorded by various agencies and can be detected on the basis of remotely sensed images, may increase the probability of disturbances such as fire and have other biological effects that society often considers undesirable. We recommend that regional land-use change coincident with each United States census be assessed. Logical covariates are project type and extent of timber harvest. If housing development along the periphery of USFP projects is greater than along the periphery of other forests, then ARB might choose to measure potential biological effects of the development (e.g., proportion of edge to interior, density of domestic animals at varying distances from the edge of USFP projects, occurrence or abundance of non-native invasive species as a function of distance from project edges or associated human infrastructure). Edge-to-interior ratios likely can be assessed on the basis of remotely sensed images, whereas changes in the occurrence or abundance of most species will require field studies.

7.4. Program-level theories of change

Stakeholders and regulators expressed concerns that implementation of the USFP may lead to displacement of timber harvest from USFP projects to other areas, a phenomenon often referred to as *leakage* (Munn et al. 2002; Ewers & Rodrigues 2008). The USFP attempts to control leakage by requiring landowners to employ sustainable harvest practices on all of their properties, including those outside USFP projects. The carbon stocks on a USFP project must be a net increase for that landowner. Also, landowners who list an improved forest management project initially may reduce the volume of timber harvested, but over time the changes in management may enable an increase in the volume of timber harvested. In these cases, there may be no leakage.

Although our working group considered whether the USFP will result in leakage, it appears there currently is no robust method of monitoring leakage. National and global timber harvest over the next century will change as human populations grow. Timber demand likely will increase. Concurrently, timber supply may decrease if trees are maintained in parks, reserves, and carbon sequestration projects. However, the global market for forest products and the many different carbon sequestration programs and reserve management strategies make it virtually impossible to measure the effect of the USFP on leakage at national or global levels. Inability to measure leakage across ownership or political boundaries similarly has constrained application of the International Union for the Conservation of Nature's Reduced Emission through Avoided Deforestation and Degradation (REDD) program (Henders & Ostwald 2012, R. Birdsey personal communication, J. Nickerson personal communication). There is no standard method for measuring leakage on REDD projects.

Henders and Ostwald defined both primary and secondary leakage from fuelwood harvest, agricultural conversion, and timber harvest (Henders & Ostwald 2012). They recognized that accounting for leakage at the international level is more difficult than accounting for leakage at smaller extents. However, they contended that among the major quantification methods, only the Verified Carbon Standard fulfilled all of the requirements for measuring leakage in REDD. If the international community ultimately agrees on metrics, then ARB may wish to reconsider whether to restrict monitoring of program-level effects to the conterminous United States.

Program-level effects are only likely if USFP projects represent a substantial percentage of the landscape. Furthermore, program-level effects may not manifest for ten or more years. Therefore, we recommend deferring monitoring until informed thresholds of relative area or time are reached.

Table 3. Recommended elements to monitor during stage one to assess whether actions consistent with theories of change are occurring. Hypothesized biological effects would not be monitored unless a second stage of monitoring was initiated.

Hypothesized environmental change	Actions to monitor	Possible metrics	Possible sources of data	Hypothesized biological effects of the actions
USFP project level				
Increased tree density relative to other managed forests that are ecologically similar	Mechanical thinning (reduces tree density)	Normalized Difference Vegetation Index (NDVI), leaf area index (LAI)	Remotely sensed images from MODIS, Landsat, and other sources	Increased probability of wildfire, disease outbreaks, and high densities of pests
	Managed fire (reduces tree density)	Fire perimeter and severity	National Interagency Fire Center	
		Burned area, detection of active fires	MODIS, MTBS	
Decrease in percent cover of	Spatial extent, intensity, and	Percent cover of shrubs	lidar (for some locations and time	Loss or reduction in quality of

shrubs and herbaceous vegetation relative to other managed forests	frequency of shrub removal		periods)	habitat for species associated with vegetation layers below the canopy
Increase in clearcutting relative to other managed forests	Planned timber harvest	Location, extent, and configuration of clearcuts	USFP listing and verification data	Loss or reduction in quality of habitat for species associated with forest and woodlands, especially forest interior
	Implemented timber harvest	Location, extent, and configuration of clearcuts	Remotely sensed images from MODIS, Landsat, and other sources	
		Carbon prices	Futures indexes	
	Number of USFP projects listed in about 2023		USFP listing data	
Increase in road construction relative to other managed forests	Construction of new roads	Number, linear distance, and density of roads	CalFire Forest Practice GIS	Loss or reduction in quality of habitat for species that avoid roads or traffic, loss or reduction in connectivity among populations of some species, increased probability of colonization by non-native invasive plants
			Remotely sensed images from Landsat and finer-resolution sources	
Regional level				
Increased proportion of late-successional forest		Area of each ecosystem that is listed	USFP listing data	Loss or reduction in quality of habitat for species associated with early successional stages
		Proportion of each ecosystem that is listed	USFP listing data	
Increased	Low-density	Location and	Remotely sensed	Loss or reduction

urbanization	housing development along perimeters of USFP projects	density of housing and associated infrastructure	images from Landsat and finer-resolution sources	in quality of habitat for species that cannot coexist with human activity
			Publicly available data on land use from LANDFIRE, NLCD, National Agricultural Statistics Service, and other sources	
Program level				
Displacement of timber harvest (leakage)	Increase in harvest in areas not included in the USFP	Monitoring not recommended at this time because standardized methods for measuring leakage do not exist		

7.5. Consensus recommendations of the working group

As described above, the working group considered diverse physical and biological variables and methods for monitoring biological effects of the USFP across multiple levels of biological diversity. The statement of work, which referenced data from remote sensing, field monitoring, and project listing and verification, initially drove the variables and methods we considered.

Remote sensing. Remotely sensed information sometimes can be used to compare patterns of land-cover or vegetation change in treated sites and reference sites. The working group initially discussed assessment of biological effects on the basis of coarse-scale attributes of vegetation structure and function derived from remotely sensed images (e.g., Landsat, MODIS, AVHRR). These variables included vegetation greenness, vegetation moisture, canopy light absorption, forest patchiness, and forest cover.

Field monitoring. At fine spatial resolution, a suite of physical variables that typically are measured in the field may be associated with biological condition. These variables include density of unimproved roads and erosion rates and sediment loads that are affected by land use. Field monitoring also may measure biological variables such as occurrence or demography of selected native and non-native species. These species may have legal protection (e.g., species listed under federal or state Endangered Species Acts) or may allow inference to ecosystem status (e.g., species that play disproportionate roles in structuring the ecosystems they inhabit; these species sometimes are referenced as keystone or foundation species). In addition, measures of vegetation structure and composition may allow inference to biological or ecosystem status. The latter measures include size distributions of trees within stands, total basal area of trees, percent composition of native trees, structural complexity of stands, and relative cover of native or non-native species.

Project listing and verification. The working group considered attributes that may be assessed on the basis of the project listing and verification process. These include site preparation and planting techniques; thinning, herbicide, and harvest treatments; salvage actions; and

infrastructure construction and maintenance (e.g., road building). These attributes also might be considered within a spatial context, such as their distances from rivers and streams.

Selecting variables to monitor. There was group consensus that any biological monitoring program should collect data on state variables (e.g., percent composition of native species, distribution of age or stage classes, structural complexity, abundance of coarse woody debris, snag density) on USFP projects and on reference sites. As described above, our directive was not to recommend methods to determine whether management of forests that are enrolled in the USFP has negative biological effects, but to recommend methods to determine whether implementation of the USFP per se has negative biological effects. Assessing biological effects of implementing the USFP requires that the same metrics be measured with the same methods on USFP sites and reference sites, and then compared statistically. As described above, the working group discussed more than 20 variables that may allow some degree of inference to biological status. Given the number of forest types that may be enrolled in the USFP and the number of native and non-native species that may be a focus of monitoring, hundreds of response variables are possible. The group also agreed that actions hypothesized to have biological effects, and associated response variables and covariates (independent variables), are likely to vary among ecosystems, making development of uniform monitoring metrics extremely challenging. The group concluded that generic, spatially extensive monitoring is highly unlikely to be informative.

The working group also identified substantial logistic concerns with using metrics described above to infer biological effects of implementing the USFP. For example, the lag time from implementation of monitoring to generation of results could be long given the slow rates of change in many forest ecosystems. Extrinsic drivers of biological status (e.g., climate change, land use in winter habitat for neotropical migrants, management near headwaters or upper reaches of streams) could make detection of USFP-driven effects not only data-intensive and costly but imprecise.

The working group concluded that use of remote sensing or field measurements to monitor the biological effects of the USFP requires a robust theory of change (i.e., a hypothesis of how enrollment in the USFP drives management actions that plausibly could have negative biological effects). The working group recommended that initial monitoring be restricted to identifying behaviors (management actions) associated with USFP enrollment. The working group concluded that establishing whether implementation of the USFP has negative biological effects requires

1. A mechanistic hypothesis why management actions driven by the USFP reasonably might be expected to have a measurable biological effect that could be considered negative.

2. Identical measurements on USFP project areas and other managed forests with comparable ecological and social attributes (i.e., matched reference sites).

3. Statistical comparison of quantitative data from USFP project areas and matched reference sites.

4. Establishing an effect size or threshold for statistical significance driven by a societal definition of the normative term *adverse*.

8. Maintenance of Data and Metadata

We strongly recommend that ARB invest promptly in electronic maintenance of data and associated metadata. Substantial data will accrue from listing and verification of USFP projects and from additional monitoring of planned actions, implemented actions, and biological responses. Metadata document the fundamental attributes of data, such as who collected the data, when and where the data were collected, what variables were measured, how and in what units measurements were taken, and the coordinate system used to identify locations. Metadata allow one to understand a data source in sufficient detail to replicate the data collection and determine whether the data are applicable to a given analysis or decision-making process. The Federal Geographic Data Committee and Dublin Core maintain detailed technical and nontechnical explanations of metadata.

It is far more cost-effective to begin maintaining data and metadata at the outset of USFP implementation and to ensure all project data and metadata are captured electronically than to wait until data synthesis and analysis becomes urgent. Well-maintained data and metadata will allow ARB or its partners to examine aggregated data at any point in time, whether to examine the current weight of evidence for a given theory of change, to compare values of response variables on USFP projects and reference sites, or for any other reason.

Metadata document the attributes of data, such as what variables were measured, who took the measurements, date and time of measurements, coordinates (and coordinate system) of the locations where data were collected, and units used to measure variables. Metadata facilitate sufficient understanding of data that data collection could be replicated. Metadata also allow one to determine whether data are applicable to a given analysis or decision-making process.

We recommend that ARB adopt metadata standards that are consistent with those of the National Spatial Data Infrastructure (NSDI). Different agencies, organizations, and research consortia have developed metadata standards that are customized but consistent with these standards. For example, Ecological Metadata Language (http://knb.ecoinformatics.org/) was developed to meet the needs of ecologists (Michener et al. 1997). Use of such standards will increase compatibility of data and metadata collected or compiled by ARB and freely available data from public sources such as NASA and the U.S. Geological Survey. It is possible that social, behavioral, and economic data that are not adequately supported by the NSDI will be collected by ARB. Accordingly, we recommend that ARB investigate the Data Documentation Initiative, an international standard for describing data from the social and behavioral sciences.

Standardized systems of data organization, storage, and retrieval facilitate compilation, discovery, accessibility, and assessment of substantial amounts of data. The identity of landowners or other owners can be masked and all confidential and proprietary information can be protected. Additionally, access permissions can be established that ensure confidentiality and privacy.

We strongly recommend that ARB ensure that the host of its data is stable and that complete backups of data and metadata are made regularly. We recommend that ARB consult with multiple experts on informatics, including those at universities and in the private sector, to identify best practices and facilitate budget estimates.

9. Recommendations

1. Quantitatively define *adverse*

- Engage social scientists, ethicists, and natural scientists in a process to identify societal values and to translate those values into quantitative thresholds of biological effects.

- Engage in a public process to define *adverse* for response variables measured during the second stage of monitoring.

- Recognize temporal changes in structure, composition, and function of forests when establishing criteria for *adverse*.

2. Use theories of change to drive monitoring

- Link all USFP project-level monitoring to an explicit, quantitative theory of change.

- Focus monitoring on plausible theories of change.

- Collect and analyze data to assess whether the sequence of events (actions and biological effects of those actions) hypothesized by the theories of change is occurring.

3. Establish an adaptive monitoring process

- Implement a monitoring program that is explicitly adaptive: establish data-collection methods, a phase in which the data are analyzed, and adjustment of data collection, analysis, and USFP attributes as necessary given the results of the evaluation.

- Implement a two-stage monitoring process. First, document whether planned or ongoing actions reflected in the USFP data are consistent with theories of change. If the first stage of monitoring indicates such actions are occurring and that actions differ between USFP projects and other managed forests that are ecologically similar, then initiate a second stage of monitoring to measure, in the field or remotely, whether hypothesized biological changes are associated with the actions. Adverse must be defined quantitatively before a sampling for stage two monitoring is designed.

- During stage one, monitor response variables that can be measured on the basis of the USFP data or other reliable public or private sources.

- During stage one, monitor both planned actions (i.e., those included in management plans) and realized actions on USFP projects to assess the extent, intensity, and frequency of the actions.

4. Address the issue of timber harvest directly

- If ARB wishes to monitor timber harvesting, then monitor length of rotations, size of clearcuts, volume of wood harvested, and construction of roads in association with timber harvest.

5. Allow program-level effects time to manifest

- Track carbon prices to determine whether there is an association among timing of most recent timber harvest, listing of reforestation projects, and carbon prices.

- Defer monitoring of program-level effects until informed thresholds of relative proportion of ecosystems included within USFP projects, or time after listing of USFP projects, are reached.

- Limit stage one monitoring of the proportion of late-successional forest to calculating the area and proportion of each ecosystem that is included within USFP projects.

- Assess regional land-use change coincident with each United States census.

6. Maintain program data and metadata electronically

- Invest promptly in maintenance of electronic data and associated metadata.

- Electronically archive all listing, verification, and monitoring data and associated metadata promptly upon receipt

- Adopt metadata standards that are consistent with those of the National Spatial Data Infrastructure (NSDI). Investigate the Data Documentation Initiative, an international standard for describing data from the social and behavioral sciences, as a source of metadata standards for data not covered by the NSDI.

- Ensure that the host of USFP data is stable and that complete backups of data and metadata are made regularly.

- Consult with multiple experts to identify feasible standards for maintenance of data and metadata and to obtain budget estimates.

7. Collect additional data on USFP projects

- Audit USFP project risk rating through the Buffer Account process to evaluate variability in risk and verify that risk ratings are accurate.

- Record tax filing status of USFP landowners as individual, for-profit organization, private operating foundation, social welfare organization, Tribe, or government unit.

- Record the proportion of each USFP project that is included in a conservation easement

10. Summary

A goal of the Adaptive Management Plan for the Cap-and-Trade Regulation is to monitor and respond to adverse biological effects caused by implementation of the Compliance Offset Protocol for U.S. Forest Projects (USFP). Such biological effects must differ from those expected given business as usual if the USFP had not been implemented. Additionally, *adverse* is a societal value judgment that must be determined by the Air Resources Board (ARB) in consultation with multiple sectors or stakeholders.

A multidisciplinary working group and additional diverse individuals with expertise in carbon sequestration, forest ecology, and monitoring and assessment agreed that there were few if any plausible scenarios in which the USFP would cause an adverse biological effect. However, we recognize ARB may wish to track data from USFP projects and other managed forests over time to verify whether the assumption of no unintentional biological effects is accurate. Accordingly, we recommend that ARB engage in a two-stage monitoring process.

We recommend that the first stage of monitoring document whether planned or ongoing actions described in the course of listing or subsequent verification of USFP projects are consistent with the theories of change. If actions are consistent with the theories of change, then we recommend initiating a second stage of monitoring that measures, in the field or remotely, whether hypothesized biological changes are associated with the actions. Matching of reference sites to USFP projects on the basis of physical, ecological, and social attributes and assessment of the counterfactual occurs during the second stage of monitoring. Implementation of the second stage of monitoring also would trigger determination by ARB of values of biological variables that would be judged adverse.

We recommend that ARB invest promptly maintenance of electronic data and metadata from USFP project listing, verification, audit, and related processes. We recommend that ARB adopt metadata standards that are consistent with those of the National Spatial Data Infrastructure and investigate the Data Documentation Initiative, an international standard for describing data from the social and behavioral sciences, as a standard for data that typically would not be characterized as biological or spatial.

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12. Definitions

Abundance. Number of individuals.

Adverse. A value judgment, based on contemporary societal standards, of a level or type of change or outcome that is undesirable.

Amenity value. Attributes of a given feature or location that provide personal enjoyment or satisfaction and therefore increase its monetary value

Assemblage. The species, generally within the same taxonomic group, that occur in the same place at the same time, but are not assumed to interact.

Biological diversity. Life at all levels of organization, from genes to ecosystems, and encompassing structure, composition (species identity), and function.

Biological effects. Effects of an environmental phenomenon or change on life at all levels of organization, from genes to ecosystems, and encompassing structure, composition, and function.

Biological status. The state or condition of a given biological attribute.

Causation. Pertaining to cause and effect.

Coarse filter. Management on the basis of ecosystems, land-cover types, or vegetation types. Species, populations, or finer levels of biological organization implicitly are assumed to be managed effectively as a result.

Composition. The identities of species in a given location during a given period of time.

Counterfactual. What would have happened in the absence of an intervention, such as a forest-management action.

Covariate. An independent variable to which a response or dependent variable is hypothesized to respond.

Demography. The study of the structure of populations, such as births, deaths, emigration, immigration, and growth rate.

Effect size. The magnitude of the change in a variable that one observes, or expects to observe, in response to a treatment or exposure to an agent of change.

Extent. The area or time period covered by a given entity.

Fecundity. The maximum potential reproductive output of an individual (usually a female) over its lifetime.

Fine filter. Management on the basis of species, populations, or finer levels of biological organization.

Forb. Non-woody flowering plant that is not a grass.

Fragmentation. The process of breaking continuous land cover, generally of the same type, into discontinuous patches.

Function. Ecological processes such as cycling of water and nutrients.

Hyperspectral. Hundreds of spectral bands that can be used to measure reflectance or absorption, which may allow for identification of features on Earth's surface.

Land cover. The biological or physical cover on Earth's surface. Land cover includes both natural features, such as dominant vegetation, rock, and water, and anthropogenic features such as agricultural fields and urban areas.

Land use. Social or economic activity associated with a given type of land cover.

Mechanistic. A causal explanation of a phenomenon.

Metadata. The fundamental attributes of data, such as who collected the data, when and where the data were collected, what variables were measured, how and in what units measurements were taken, and the coordinate system used to identify locations.

Metapopulation. A group of spatially distinct populations of a given species that collectively is maintained by repeated extirpation (local extinction) and recolonization of individual populations.

Phenology. The timing of seasonal events in the life cycle of plants and animals.

Physical status. The state or condition of a given physical attribute.

Program level. Acting at the level of the US Forest Protocol.

Recruitment. The process by which young are added to a population by reproduction from reproductively mature individuals in the population.

Region level. Acting at the level of ecosystems or relatively large geographic areas, such as states or groups of states.

Resolution. The smallest unit that can be distinguished or for which data are collected.

Response variable. Dependent variable, or the entity that is the ultimate focus of assessment.

Selective harvest. Removal of individual trees or other plants on the basis of criteria such as size, age, or identity.

Spatial distribution. Typically, the aggregate locations and configuration where a given environmental element, such as a species or land-cover type, occurs.

Spatial extent. The area over which an environmental element occurs or observations are made.

Spatial heterogeneity. The extent to which ecological or physical elements, such as land cover or mountains, are distributed unevenly in space.

Spatial resolution. The smallest area for which values of a given variable can be measured or estimated.

Species persistence. The probability that a species will remain extant. Typically estimated with respect to a given period of time and sometimes with respect to a given location.

Species richness. The number of species in a given location and time period.

Spectral band. A group of similar wavelengths.

Spectral resolution. The number of visible or infrared bands, or the smallest difference among wavelengths that can be differentiated.

Spectral signature. A distinct pattern of electromagnetic radiation associated with a given object or feature.

State variable. A variable that characterizes the state of a non-stationary system.

Structural complexity. The diversity of vegetation layers, such as canopy, shrubs, and understory.

Structure. The distribution and abundance of different ecological features, such as layers of vegetation.

Succession. The predictable replacement of communities of species as time since disturbance increases.

Temporal resolution. The smallest unit of time that can be distinguished or for which data are collected.

Theory of change. A sequence of events that is expected to occur as a result of an intervention.

USFP project level. Produced by or occurring within the boundaries of a USFP project.

Appendix A. Summary of California's Compliance Offset Protocol for U.S. Forest Projects provided to interview subjects.

Goals of the Forest Offset Protocol

The goal of the Compliance Offset Protocol for U.S. Forest Projects (Forest Offset Protocol) is to ensure that net reductions in emissions of carbon dioxide accomplished by a Forest Project are accounted for completely, consistently, transparently, and accurately. A Forest Project is a planned set of activities designed to decrease atmospheric carbon dioxide by increasing or conserving forest carbon stocks.

Types of forest projects

Three types of projects are eligible for listing under the Forest Offset Protocol. The first are *restoration projects*: reforestation of public or private land on which healthy trees have not been harvested within the past 10 years or following a major disturbance. These projects must plant trees or remove impediments to natural reforestation on land that either had < 10% tree canopy cover for ≥ 10 years or was exposed to a disturbance that removed ≥ 20% of the aboveground live biomass of trees.

The second type of project, *improved forest management*, maintains or increases carbon stocks on private or public forest relative to baseline levels of carbon stocks. Projects must be on land with > 10% tree canopy cover and employ so-called natural forest management practices (see below). Allowable activities include increasing the average age or density of trees, removal of diseased or otherwise unproductive trees, and removal of shrubs and short-lived trees.

The third type of project, *avoided conversion*, prevents conversion of privately owned forest to non-forest via a conservation easement or transfer to non-federal public ownership. Tree planting and harvesting may be allowable.

Allowable or required management actions

<u>Natural forest management</u>. Projects are required to employ natural forest management practices, defined as promotion and maintenance of a diversity of native species of mixed ages as measured at multiple extents and resolutions. Native species are considered to be those occurring naturally rather than introduced by humans (post-European settlement). Where supported by peer-reviewed research, and in accordance with an adaptation plan that has been approved by state or federal agencies or a transparent process of public review, native trees may be planted outside of their current distribution as a response to projected climate change.

All forest projects must maintain or increase standing live carbon stocks over the project life, progress toward a composition and distribution of trees that is consistent with native forest composition and soil type, and support structure and function of habitat for native plants and animals.

Native species management. Demonstrating establishment and maintenance of native species and natural forest management is defined by > 95% of standing live carbon stored in native species at initiation of a project, or composition that reasonably could be expected to be meet this criterion within 25 years.

Multi-species management. For improved forest management and avoided conversion projects, no single species may have a percent composition greater than that established by the Air Resources Board (ARB) for a given ecosystem type (e.g., Allegheny & North Cumberland Mountains Northern Hardwood; ecosystem types are referenced as Assessment Areas). For reforestation projects, planting of seedlings may not result in a percent composition of any one species that is greater than that established by ARB for a given Assessment Area.

Distribution of age classes. Within the smaller of the project area or 10,000 acres of a watershed, no more than 40% of forested area can be < 20 years of age unless there has been a major disturbance in the area. Offset projects that employ even-aged management practices may not harvest stands > 40 acres.

Maintenance of dead woody biomass. Projects must meet criteria for vegetation structure:

- In areas without either salvage harvest within the past year or evidence of active removal of lying dead wood, ≥ 1 metric ton of carbon per acre must be lying dead wood or the equivalent of ≥ 1% of standing live carbon must be standing dead wood (whichever is greater).
- In areas without salvage harvest within the past year and evidence of active removal of lying dead wood, ≥ 2 metric tons of carbon per acre must be lying dead wood or the equivalent of ≥ 1% of standing live carbon must be standing dead wood.
- In areas with salvage harvest within the past year and no evidence of active removal of lying dead wood, ≥ 2 metric tons of carbon per acre must be standing dead wood.
- In areas with salvage harvest within the past year and evidence of active removal of lying dead wood, ≥ 4 metric tons of carbon per acre must be standing dead wood.

Maintenance of standing live carbon. Standing live carbon stocks must be maintained or increased over any 10 consecutive years unless the decrease meets one of the following criteria.

- Substantial increases in resistance to wildfire, insect damage, or diseases implemented on the basis of methods supported by peer-reviewed literature.
- A planned balancing of age classes detailed in a long-term management plan.
- Part of normal silviculture cycle for ownership of < 1000 acres of forest.
- Unintentional processes such as wildfire, disease, flooding, wind-throw, insect damage, or landslides.

Sustainable harvest. Forest Owners are required to employ sustainable long-term harvesting practices in addition to natural forest management practices on both the Project Area and any other non-listed areas they own. Projects may achieve the criteria for sustainable harvest in one of three ways: (1) certification of the forest owner by the Forest Stewardship Council, Sustainable Forestry Initiative, or Tree Farm System, (2) adherence to a renewable long-term management plan that is monitored by a state or federal agency and demonstrates permanently sustainable harvest levels, or (3) maintenance of ≥ 40% canopy cover over each 40 acres of forest included in the Project Area.

Adjacent-stand harvest. Stands adjacent to recently harvested stands must not be harvested with even-aged methods until the average age of trees in the harvested stand is ≥ 5 years old, or the average height of trees in the harvested stand is ≥ 5 feet.

Appendix B. Guidelines for topics addressed during discussions with interview subjects.

We did not follow a formal interview protocol or send questions to interview subjects in advance of telephone conversations. The questions below were our internal guidelines for topics to address during the discussion if possible.

1. What is your experience with the USFP?

2. What is your professional position and experience with carbon sequestration in forests?

3. Some stakeholders have questioned whether the USFP will protect the integrity of forested ecosystems. What are your thoughts on the extent to which the USFP is likely to protect the integrity of forested ecosystems?

4. What management actions do you recommend tracking to gauge whether they reduce biological status on USFP sites or in surrounding areas?

5. Do you anticipate any other biological effects of establishing or managing forests for carbon sequestration, relative to other ongoing land uses, that might be considered negative? What management actions might lead to these effects?

6. It has been suggested that owners of USFP project sites could harvest stands, leave them to regenerate for 10 years, and then enroll them as reforestation sites. Do you think this is likely? If so, what might the biological effects be?

7. It has been suggested that the USFP may create an incentive to increase tree density and thus increase the probability of tree mortality through pests, pathogens, or disturbance. Given your understanding of the USFP, do you think that substantial increases in tree density are likely?

8. Do you have any other thoughts about the USFP and its potential biological effects?

9. Do you recommend we speak with any other experts?

Appendix C. Recommended data to obtain from the USFP listing and verification process and rationale for the recommendation.

Planned management actions

Clearing of shrubs and herbaceous understory. Allows assessment of whether implementation of the USFP may change quantity and quality of habitat for species of plants and animals associated with these vegetation layers.

How management will meet the definition of Natural Forest Management, including species composition, distribution of age classes, and assessment of standing and lying dead wood. May be useful for matching reference sites.

Reduction of tree density. Allows assessment of whether implementation of the USFP may be associated with increases in the probability of fire or outbreaks of diseases or pests.

Timber harvest. Allows assessment of whether implementation of the USFP may result in trade-offs among habitat quantity and quality for different species of plants and animals, including non-native invasive species. Also may be useful for matching reference sites.

Actions in riparian zones. Not associated with a theory of change, but might affect extent of erosion and habitat quality for some species of plants and animals (recommended during the interview process).

Removal of downed wood. Not associated with a theory of change, but might affect habitat quality for some species, extent of erosion, and rates and quantities of nutrient cyling (recommended during interview process).

Implemented management actions

Clearing of shrubs and herbaceous understory

Actions after disturbances, such as species composition of plantings and salvage logging. Not associated with a theory of change, but the choice of species that are replanted may affect habitat quality for some species of plants and animals, resilience of the ecosystem to natural disturbances, and primary productivity (recommended during interview process).

Actions in riparian zones

Removal of downed wood

Biological elements

Ecosystems within the project's boundaries. May be useful for matching reference sites.

Mean age of trees in a given stand. Allows assessment of whether implementation of the USFP may change probabilities of fire or outbreaks of diseases or pests. Allows assessment of whether implementation of the USFP may result in trade-offs among habitat quantity and quality for different species of plants and animals.

Reversal risk rating and contribution to the Forest Buffer Account. May be useful for matching reference sites. Also will allow evaluation of variability in risk and verification that risk rating is accurate.

Social or economic elements

Date of USFP project listing. May be useful for matching reference sites.

Number of easements on USFP projects. May affect future management options.

Number of USFP projects listed in about 2023, 10 years after implementation of the USFP. Allows assessment of whether implementation of the USFP may have created an incentive to harvest trees, then enroll reforestation projects.

Project boundaries and governance jurisdictions (e.g., state, counties, towns). May be useful for matching reference sites.

Tax filing status of landowners. May be useful for matching reference sites.

Whether any part of the project area has been included in another offset program (e.g., Climate Action Reserve). May be useful for matching reference sites.

Appendix D. Recommended data to collect that are not currently collected during the USFP listing and verification process and rationale for data collection.

Biological elements

Density of trees in managed forests that are in the same ecosystem as USFP projects. Allows assessment of whether implementation of the USFP may drive changes in management actions.

Land cover within and surrounding USFP projects, including urbanization. Allows assessment of whether implementation of the USFP may be associated with increases in low-density housing on the periphery of USFP projects.

Proportion of late-successional forest on USFP projects and other managed forests that are in the same ecosystem as USFP projects. Allows assessment of whether implementation of the USFP may result in trade-offs among habitat quantity and quality for different species of plants and animals.

Road construction. Addresses concerns raised in public comments.

Shrub cover in managed forests that are in the same ecosystem as USFP projects. Allows assessment of whether implementation of the USFP may drive changes in management actions.

Timber harvest. Allows assessment of changes in clearcutting.

Social or economic elements

Carbon prices. May affect incentives for different management actions, including timber harvest.