TRIM.FaTE USER'S GUIDE
MODULE 6: IMPLEMENTING BIOTA IN A TRIM.FaTE SCENARIO[1]

1. OVERVIEW

This module describes concepts, properties, and steps important for the user to understand when implementing biota in a TRIM.FaTE scenario. The flow chart presented in Figure 1 provides an overview of an iterative approach for conceptualizing an ecosystem and the associated actions the user performs to implement the biota in a TRIM.FaTE scenario. It illustrates how some iterations may be needed in designing the food web and/or biotic compartments or link properties to ensure reasonable total biomass and distribution of biomass across trophic levels. The concepts underlying these decisions and associated modeling activities are described in the sections of this module. The flexibility of TRIM.FaTE enables many approaches for modeling an ecosystem.

There may be TRIM.FaTE applications (e.g., where animal body burden or intake rates are not of interest) where biota will not be included in the scenario. That may be the case where the focus of the simulation is prediction of chemical concentrations or mass in soil or sediment. In some cases, depending on the precision of the user's needs and whether chemical mass or concentration is of interest, it may be important to include only terrestrial and aquatic vegetation.[2] For other TRIM.FaTE applications, the user's interest in animals may be limited to those in or associated with aquatic ecosystems. This module discusses considerations in implementing these biota, as well as considerations associated with implementing biota in a simulation involving a terrestrial ecosystem or both terrestrial and aquatic ecosystems.

The information provided in this module is based on the design of and experience with TRIM.FaTE to date. Note that inclusion of ecosystems, and particularly terrestrial food webs, in mass-balanced modeling of chemical transport through ecosystems is a fairly recent area of activity. There are undoubtedly many issues and questions that have not been addressed or considered here.[3] Thus, the user is reminded of their responsibility for assessing the performance of their TRIM.FaTE scenario (with biota) for their application. Additionally, the information presented in this module assumes that the biotic compartment types used in a

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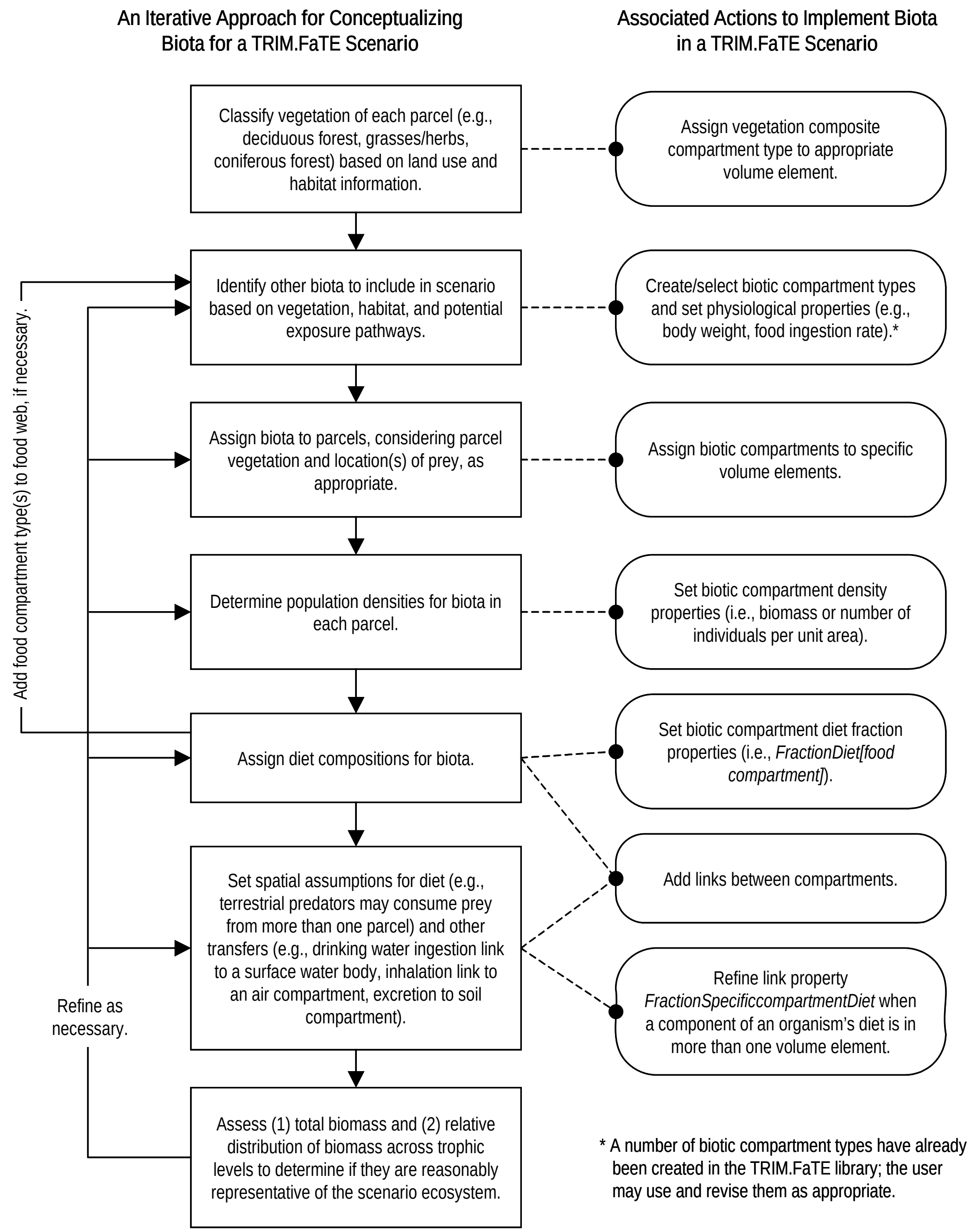
[1] Descriptions of library-specific algorithms and properties presented in this module pertain to the July 2005 version of the TRIM.FaTE Public Reference Library.

[2] Early evaluations performed with TRIM.FaTE indicated that the presence of animal compartments did not have large effects on soil or sediment concentrations or mass (EPA 2002a).

[3] Section 4.3 of the Evaluation of TRIM.FaTE, Volume I (EPA 2002a) examines the potential influence of biotic compartments on the mass balance of modeled chemicals using one series of simulations for four different chemicals in a very simplified model set-up. This information may be helpful to users as they establish a series of test scenarios/runs to assess their conceptual models for the aquatic and terrestrial ecosystems and to verify their implementation of those models in TRIM.FaTE.

Figure 1
Overview of an Approach to Conceptualizing and Implementing Biota in TRIM.FaTE



scenario have already been created in the library associated with that scenario. Refer to Section 5 of Module 4, Adding New Components to a Library, for guidance on creating new compartment types (e.g., to create a new compartment type for an animal or plant not currently represented).

The remainder of this module is organized in six sections: establishing the terrestrial vegetation (Section 2), establishing the aquatic biotic compartment types and food web (Section 3), establishing terrestrial animal biotic compartment types and food web (Section 4), reviewing and evaluating the biotic systems (Section 5), and seasonal issues (Section 6). References (Section 7) and calculations concerning aquatic biomass trophic pyramids (Appendix A) also are provided. Sections 2 through 6 of this module should not be interpreted as step-by-step instructions to a user; rather, they discuss important considerations in implementing biota in a TRIM.FaTE scenario. As illustrated in Figure 1, implementation of biotic compartments in a TRIM.FaTE scenario requires careful, often iterative evaluations of the relationships among the compartments and their properties.

2. ESTABLISHING THE TERRESTRIAL VEGETATION

In developing the layout of the land surface parcels for a scenario, the user typically will have considered land-cover and/or land-use information (described further in Module 5, Developing the Spatial Layout). This information is also used to assign a vegetation type to each surface soil volume element. The vegetation type determines which algorithms and inputs will be used to model terrestrial plants. In the current TRIM.FaTE library, only one vegetation type can be assigned per surface soil volume element. The user needs to consider the implications of this on the parcel layout or, if considered appropriate, augment the library with an alternative approach. The four vegetation types that are in the current TRIM.FaTE library are deciduous forest, coniferous forest, grasses/herbs, and agricultural (e.g., crops). A surface soil volume element can also be modeled as having no vegetation (e.g., if the area is highly developed or paved, or if the user wants to omit terrestrial plants from a model run).

USER TIP: INTERDEPENDENT PLANT LEAF PROPERTIES

Three leaf properties are interdependent but are entered as separate values in the current library:

- **Leaf area index** (LAI) (property *AverageLeafAreaIndex_No_Time_ Dependence*; units of m^2[leaf]/m^2[area]);
- **Mass of fresh leaf per unit area** (property *WetMassperArea*; units of kg[fresh leaf]/m^2[area]); and
- **Density of foliage, wet weight** (property *WetDensity*; units of kg[leaf]/m^3[leaf]).

It is up to the user to ensure consistency among these parameters. These parameters are related as follows:

$$\text{wet mass per unit area} = \text{LAI} \times \text{leaf thickness} \times \text{density of foliage}$$

Note that leaf thickness (in meters) is not a parameter in TRIM.FaTE. Values for leaf thickness may be measured or obtained from the literature.

The grasses/herbs and agricultural vegetation types are modeled using four compartment types: particle on leaf, leaf, stem, and root. Because of uncertainties in modeling transfer processes, the current TRIM.FaTE library does not include root and stem compartments for woody vegetation types (i.e., deciduous and coniferous forest vegetation types include only particle on leaf and leaf compartments). The particle on leaf compartment type (i.e., "leaf particle" in the current TRIM.FaTE library) accounts for chemical deposited onto the leaf surface. Particles on the leaf surface can be washed off during rain to the surface soil or blown off back into the air. Chemical in the particles can be absorbed into the plant leaf compartment.

The current TRIM.FaTE library includes a leaf compartment property, *AllowExchange*, that can be set as a constant or time-varying property. This allows the user to specify that coniferous forest compartments have leaves year round, while deciduous compartments can be specified to only have green leaves present (and available to herbivores) during the growing season. Seasonality is discussed in more detail in Section 6.

3. ESTABLISHING THE AQUATIC BIOTIC COMPARTMENT TYPES

For scenarios that include rivers, streams, lakes, or other surface water bodies, it is up to the user to identify the appropriate biotic compartment types for inclusion in each modeled water body of concern (Section 3.1). The user then must "construct" the aquatic ecosystem food webs to include those compartments and to reflect appropriate food web relationships, including other compartments as needed (Section 3.2). The user also must represent the distribution of biomass among components and trophic levels of the food web (Section 3.3).

3.1 Assigning Aquatic Biota Compartments to Surface Water Compartments

For risk assessment purposes, fish that might be consumed by humans and the fish and benthic organisms that wildlife might consume are generally the groups of primary interest in an aquatic ecosystem. Concentrations of the chemical(s) in these groups are needed to estimate exposure and risk for the humans and wildlife that consume them. To adequately estimate contaminant concentrations in these compartment types in TRIM.FaTE, all supporting trophic elements and the links among elements also must be included. Thus, to ensure appropriate estimates of chemical mass transport and fate in a given surface water compartment, it is important that the sum of the biomass across the aquatic biota compartment types included in that compartment approximate the total biomass in the surface water body being modeled.

To begin assigning aquatic biota compartment types for a scenario, the user should develop a conceptual model of the aquatic ecosystem in the surface water body of interest that describes the food web to be modeled for that water body. A conceptual model that identifies the aquatic biotic compartment types needed and the trophic links among them will help the user correctly implement the compartments in TRIM.FaTE. This remainder of this section addresses the aquatic biotic compartment types; Section 3.2 addresses the trophic links among them.

There are several aquatic biota compartment types currently available in the TRIM.FaTE library that the user could implement to construct up to a "four-trophic-level" aquatic ecosystem. These trophic levels and the compartment types available in the library to represent them are described below in order of increasing trophic level.

Primary producers. In aquatic ecosystems, several different types of plants can serve as primary producers: small planktonic plants (e.g., algae), larger plants (e.g., macrophytes) that either float on the water surface or are attached to the substrate in the littoral zone (e.g., submerged aquatic vegetation or SAV), or emergent vegetation with roots into the substrate (e.g., cattails). Two types of aquatic plants are represented in the current TRIM.FaTE library: algae and macrophytes. In the current library, suspended algal cells (e.g., green, blue-green, diatoms) are modeled as a phase of the surface water compartment. To reflect the contribution of primary production to the detritus in the sediment bed, TRIM.FaTE models the deposition of a portion of the algae and the chemical it contains to the sediment bed. Macrophytes are modeled as a separate compartment in the surface water volume element. A macrophyte compartment type can be assigned to any surface water volume element in the scenario as appropriate.

Primary consumers. In aquatic ecosystems, primary consumers include herbivores and detritivores. In applications of TRIM.FaTE to date, the primary consumers have been represented by a *benthic invertebrate* compartment type for the animals that feeds on detritus in the benthos and by a *water-column herbivore fish* compartment type for animals that rely on primary production in the water column for their food. If macrophytes are included, the user might want to add a compartment representing primary macrophyte consumers (e.g., snails, grass carp). Alternatively, the user may modify or add algorithms for macrophyte consumption by either of the two existing primary consumer compartment types. Note that zooplankton are not explicitly represented in the current TRIM.FaTE library; instead, they might be considered to exhibit the same chemical concentrations as the algal phase of the surface water.

Secondary consumers. In a simplified aquatic food web (or chain), the secondary consumers are those somewhat larger species (e.g., panfish) that consume the herbivores and detritivores. Many secondary consumers might also consume plant materials. In applications of TRIM.FaTE to date, the secondary consumers generally have been represented by the *benthic omnivore fish* compartment type in the benthos and the *water-column omnivore fish* compartment type in the water column.

Tertiary consumers. Tertiary consumers are those species that feed predominantly on secondary consumers, although they generally also consume lower trophic-level organisms, creating the web-like transfer of materials and energy in the aquatic ecosystem. In applications of TRIM.FaTE to date, the tertiary consumers have been represented by the *benthic carnivore fish* and *water-column carnivore fish* compartment types. These are the largest and highest trophic level fish in the aquatic ecosystems modeled to date. The carnivore compartment types would include the larger sport fish.

In selecting the biotic components to represent an aquatic ecosystem, the user may choose to use or to adapt the compartments that already exist in the TRIM.FaTE library (see above) or to develop new compartments. Note that not all surface water bodies are large enough or have sufficient primary productivity to support a fourth trophic level (or even a third trophic level). For such surface water bodies, those trophic levels would not be included in the conceptual model. To reduce model runtime, the user may want to create the fewest number of biotic compartments that can adequately represent the food web supporting the highest trophic level species or group(s) in the water body.

As described in Section 6 of the TRIM.FaTE Technical Support Document, Volume II (EPA 2002a), and Section A.2 of the Addendum to Volume II, the movement of chemical through the fish compartment types is estimated using a bioenergetic model of chemical uptake, metabolic degradation, and excretion. Thus, each fish compartment type includes several compartment-specific properties (e.g., body weight, number of fish per meter squared, food ingestion rates, water clearance over the gills) and chemical- and compartment-specific properties (e.g., chemical assimilation efficiency, metabolic degradation rate, excretion rate). For each fish compartment type, the user must check that the values or equations included for these properties are appropriate for the species or group of species represented by the compartment type.

In applications to date, there have not been efforts to represent age-structured fish populations or to trace the evolution of a fish species' foraging behavior as it ages and grows in size. Nor has "growth dilution" been modeled as one of the processes influencing the level of bioaccumulation of a chemical in fish. Users wanting to incorporate such refinements would likely need to construct additional aquatic biota compartment types and to define the relationships among them.

3.2 Defining the Aquatic Food Web

Each aquatic animal compartment that is added to a scenario surface water compartment should be accompanied by and linked to biotic compartments from which it gains and loses chemical mass through trophic interactions (i.e., compartments must be included to account for key predator and prey relationships). The user specifies all of the trophic-level transfers from the primary producers through the highest-level consumers in the surface water body being modeled. The resulting conceptual model basically represents an aquatic community food web and assists the user in implementing and checking the aquatic biota compartments and links among them in a TRIM.FaTE scenario. For example, the user's conceptual model might depict the diet of an omnivorous fish as consisting of macrophytes, benthic invertebrates, and water column herbivores in specified proportions that reflect the typical diet of some abundant species of omnivore. Alternatively, the user might define more than one omnivorous fish compartment type to represent species with different foraging patterns or diets (e.g., to determine which type of diet results in the highest chemical concentrations in the fish) to match their conceptual model.

In applications of TRIM.FaTE to date, a few "shortcuts" have been employed to simplify the model of an aquatic ecosystem. The default settings in the *water-column fish herbivore* compartment in the current TRIM.FaTE library specify that the fish obtain all of their diet from algae, although in reality most small fish would be consuming algae and zooplankton or just zooplankton. As noted above, zooplankton have not been explicitly modeled as a separate trophic group. Second, given the types of data typically reported in the literature for uptake of contaminants by benthic organisms, a single partitioning model, instead of a bioenergetic model, has been used to simulate the uptake of chemical from both sediment pore water and food (detritus) by the *benthic invertebrate* compartment.

The current TRIM.FaTE library contains a set of fish dietary uptake algorithms specific to common occurrences of predator-prey relationships among the existing fish compartment types. In specifying the diet for a fish compartment, the user will want to confirm the existence of algorithms to support the desired trophic link between the compartments. If a new compartment type is added or an existing compartment type renamed (e.g., to represent a site-specific trophic group), the user will need to ensure that algorithms are added or revised to reference the newly named compartment type. If an algorithm does not exist, the user can create one based on other similar types of algorithms, if appropriate (see Module 4, Adding New Compartments, for information about adding algorithms). If the necessary algorithm changes are not made, TRIM.FaTE will report them as errors during the verification step.

In the current TRIM.FaTE library, the user specifies the diet of a fish compartment type using the property *FractionDiet[food compartment]*. This compartment property specifies by mass fraction, on a wet weight basis, the different components of the animal's diet. Food source compartments for a particular fish consumer compartment are substituted for the "food compartment" value in brackets (e.g., *FractionDietBenthicInvertebrate*). For example, if the user wants to specify that the *water-column omnivore fish* diet consists of 20 percent benthic invertebrates (by wet weight), the value of the *FractionDietBenthicInvertebrate* property for the *water-column fish omnivore* compartment would be set to 0.20. The sum of the different *FractionDiet[food compartment]* values for a given consumer compartment must equal 1.0. In the example above, if the *water-column omnivore fish* diet consisted of only *benthic invertebrates* and *water-column fish herbivores*, then the *FractionDietWaterColumnHerbivore* would have to equal 0.8 so that the sum of the two *FractionDiet[food compartments]* equals 1.0.

If the user assumes that the consumer has the same diet in all surface water bodies in a given scenario (e.g., if the *FractionDietBenthicInvertebrate* and *FractionDietWaterColumnHerbivore* of the *water-column fish omnivore* compartments should be the same in all surface water compartments), then the *FractionDiet[food compartment]* property can be most efficiently set in the TRIM.FaTE library before adding the compartments to the scenario. If, alternatively, this property is to vary by surface water body in a scenario, the values will need to be assigned to the compartments in the different surface water volume elements in the scenario. Refer to Module 1 for more information on setting values of TRIM.FaTE properties.

Finally, if a significant portion (e.g., at least several percent) of the fish in any compartment type are "harvested" by non-aquatic animals (e.g., by humans[4] or wildlife), then those non-aquatic biotic components should also be included in the TRIM.FaTE scenario to ensure an appropriate distribution of chemical mass within the aquatic system and appropriate movement of chemical mass out of the aquatic ecosystem and into the terrestrial ecosystem.

3.3 Assigning Total Biomass Density and Biomass Densities Across Trophic Levels

The estimates of transfer of chemical mass and the resulting concentrations of chemical in different biotic compartment types at different trophic levels depends in part on the relative distribution of biomass among those compartment types. Thus, it is important that the relative biomass in different trophic compartment types are as realistic as possible and that the total biomass in the system is approximated by the sum of the biomass in each compartment type in the surface water volume element.

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[4]Although TRIM.FaTE is not intended to model humans, a sink compartment can be developed and linked to a fish compartment to simulate human fishing pressure. See section 4.2 for further discussion of this concept (with regard to hunting and terrestrial species).

It is up to the user to specify a reasonable distribution of mass among trophic compartments and total biomass in the surface water compartment. Each aquatic animal compartment has two properties that, when multiplied, together specify the biomass density for that compartment: (1) the number of individuals per square meter ($\#/m^2$) and (2) body weight (*BW*) per individual (kg[animal wet weight]). The user needs to set the values for those two properties in each compartment. If using an existing compartment type in the TRIM.FaTE library, the user is required to set only the $\#/m^2$, but could change the existing value for *BW* in the compartment if needed. If the literature reports fish density, for example, in units of fish biomass per unit area (e.g., kg[fish wet weight]/m^2), the user can convert the value to the units required by TRIM.FaTE by dividing the biomass density by the value used for *BW* (kg[fish wet weight]) and by making any other calculations necessary to account for wet versus dry weight and/or different units. When setting the values that determine wet weight animal biomass for a compartment, there are three conditions that the user should consider:

TROPHIC PYRAMIDS

The transfer of energy from food to the consumer organism is never 100 percent, and depending on the organisms involved, can be closer to 10 percent or less because the bulk of the ingested energy is lost as heat. Ecologists have depicted this phenomenon using “pyramids” of energy flow (e.g., kcal/m^2-year) at succeeding trophic levels. With primary producers at the bottom of the pyramid, the energy production in the subsequent upper trophic levels generally decreases by a factor of about 10 (or more) at each successive level (Odum 1971).

If the animals in a given ecosystem are generally the same size and process energy at roughly the same rate, the pyramid of energy would translate into a structurally similar pyramid of standing biomass. However, in ecosystems in which there are smaller organisms with faster energy throughput at the lower trophic levels, as is the case in many aquatic ecosystems, the energy pyramid translates into a pyramid of standing biomass in which the biomass represented at subsequent trophic levels can decrease by a factor of less than 10 (Odum 1971), for example by a factor of 2 or 3, as for the aquatic ecosystems evaluated for TRIM.FaTE applications (see Appendix A of this module). In some types of ecosystems, the biomass pyramid can even be inverted.

(1) The values of $\#/m^2$ and *BW* in each animal compartment type should account for the total biomass of animals that the compartment type is intended to represent;

(2) The entire fish biomass in the surface water body being modeled should be approximated and distributed among the modeled fish compartments; and

(3) The distribution of biomass among the different trophic compartments results in a trophic biomass pyramid that is reasonable for that aquatic ecosystem (see text box above).

For example, it would not suffice to define the values of $\#/m^2$ and *BW* for a *water-column omnivore fish* compartment type intended to represent all such species in that trophic group as a whole in the surface water body based on a population study of only one of the species. The biomass of the one fish species might be only a fraction of the biomass of all of the fish omnivores in that surface water body. As a consequence, the modeled movement of chemical mass out of the dietary compartments to the *water-column fish omnivore* compartment type would be less than expected in the actual water body, and the chemical concentrations in the dietary compartments (e.g., benthic invertebrates, macrophytes) could be overestimated. In this example, biomass measures for the individual species would need to be added to biomass measures for other species represented in the same compartment type. The same logic could apply to a benthic invertebrate compartment. If this compartment type is included as a primary consumer in a TRIM.FaTE scenario, the user may need to account for the biomass of *all* benthic invertebrates (i.e., insects *plus* bivalves and other appropriate biota) in the properties for that compartment.

4. ESTABLISHING THE TERRESTRIAL ANIMAL COMPARTMENT TYPES

For the terrestrial volume elements to which the user has assigned natural or semi-natural vegetation compartments (e.g., herbs/grasses, deciduous forest, coniferous forest), it is up to the user to determine what animal compartments should be represented in each (Section 4.1). Once the animal compartments in each volume element have been established, the user needs to specify the trophic links between biotic compartments within a single volume element as well as links between compartments in adjacent volume elements (including the aquatic diet of any semi-aquatic birds or mammals) (Section 4.2). The user also must ensure that the ratios of biomass of predators to their prey are reasonable (Section 4.3). In some instances, the user might want to allow some animals to consume either clean or highly contaminated food sources from outside the modeling region (Section 4.4).

Note that for some applications, it may be sufficient that the only terrestrial biotic compartments included in the scenario are the plant compartments (e.g., where animal body burden or intake rates are not of interest and the focus of the simulation is to predict chemical concentrations in soil). In previous evaluations of TRIM.FaTE, the presence of animal compartments did not greatly affect chemical concentrations (or mass) in soil (EPA 2002a).

4.1 Assigning Animal Compartments to Volume Elements

It is up to the user to identify the appropriate animal compartments (if any) for inclusion in the vegetated volume elements. In assigning wildlife compartments to a scenario, the user will need to consider several factors:

(1) *The vegetation and habitat "created" in the TRIM.FaTE scenario by the designation of vegetation type and assignment of other wildlife compartments and the habitat preferences of the animal groups of interest.* For example, a vole compartment might not usually be associated with a volume element for which the vegetation compartment is deciduous forest because ground-level grasses/herbs (versus solely deciduous forest) would be the voles' preferred habitat. The vole compartment could be associated with a volume element containing a deciduous forest composite compartment if the vole's diet is designated as coming from an adjacent volume element with herbs/grasses.

(2) *Whether a chemical is likely to biomagnify in the terrestrial ecosystem (i.e., whether the chemical concentration in biota is likely to increase with increasing trophic levels).* Biomagification is most likely for those chemicals that are not metabolized and are excreted very slowly (if at all) by terrestrial animals. For

chemicals that might biomagnify (e.g., dioxins, methylmercury), the user generally will need to include the top predators of potential concern in the modeling region for the ecological risk assessment. For chemicals that are known not to biomagnify in terrestrial ecosystems (e.g., chemicals readily metabolized by birds and mammals), the user might not need to include top predators to evaluate ecological risks. It may be appropriate for the user to run a test simulation to confirm this for their application.

(3) *Whether a chemical is likely to bioconcentrate or biomagnify in aquatic ecosystems.* For these chemicals, the user generally will need to include those birds and mammals that obtain some fraction of their diet from aquatic sources.

(4) *Whether some species are notable for high biomass density in the modeling region (e.g., migratory bird stopover) and therefore might significantly affect the distribution of chemical among the vegetation and abiotic compartment types.*

To begin work on assigning animal compartments to volume elements, the user should develop a conceptual model that includes the species/groups of concern and the trophic elements (i.e., species/groups) required to support those species. The conceptual model should therefore include both the animal compartments of interest and the trophic links between those compartments and the primary producers in the ecosystem. The conceptual model of the compartment types and trophic links among them will help the user implement and evaluate the ecosystem in the TRIM.FaTE scenario. The remainder of this section addresses the wildlife compartment types; Section 4.2 addresses the trophic links among them.

The user can implement or adapt the bird and mammal compartment types currently in the TRIM.FaTE library or develop new wildlife compartment types. The terrestrial (and semi-aquatic) trophic levels and the animal compartment types available in the current TRIM.FaTE library to represent them are described below in order of increasing trophic level.

Note that the primary producer trophic level in terrestrial ecosystems is represented by the *plant* composite compartments in the TRIM.FaTE library. When plant leaves (and the particles on leaves) fall to the ground at the end of the growing season ("litter fall," Section 6.2), the mass of chemical contained

ASSIGNING SEMI-AQUATIC WILDLIFE TO LAND OR WATER VOLUME ELEMENTS

Some semi-aquatic wildlife are assigned directly to the surface water volume elements that also contain the compartments from which they obtain their diet (e.g., loons). These species generally are those that consume all of their prey from aquatic sources and are not restricted to the shoreline when foraging. Literature values for the population densities of these species often are reported in units of number of foraging individuals per unit area of surface water.

Most semi-aquatic wildlife are assigned to surface soil volume elements adjacent to surface water volume elements. These species generally are those that obtain a portion of their diet from terrestrial sources (in the surface soil volume element to which they are assigned). These species also include species that are restricted to the shoreline when foraging even though all of their diet might consist of aquatic prey (e.g., kingfishers). Literature values for population densities of these species tend to be reported in numbers of individuals per length of shoreline, except in extended wetland-like habitats, where numbers per unit area is the more common metric.

in the plant leaf and particles on leaf compartments is transferred to the surface soil compartment.

Primary consumers. As in the aquatic systems, in terrestrial ecosystems, primary consumers include herbivores and detritivores. In applications of TRIM.FaTE to date, the primary herbivores have been represented by different species of birds or mammals (e.g., a *white-tailed deer* compartment type). The primary detritivores have been represented by an *earthworm* compartment type in the root-zone soils and a *soil arthropod* compartment type in the surface soils. See Table 3-1 of the TRIM.FaTE TSD, Volume I (EPA 2002c).

Secondary and tertiary consumers. In terrestrial ecosystems, many secondary consumers (animals that consume primary consumers) also consume plant materials (e.g., seeds) depending on the season and local availability. For example, many seed-eating birds consume insects and feed insects to their young during the reproductive season. It also is true that many tertiary consumers feed from several different trophic levels. In applications of TRIM.FaTE to date, the secondary consumers generally have been represented by individual wildlife species compartments (e.g., a *short-tailed shrew* compartment type that feeds on earthworms and soil arthropods). The user might develop or use an existing animal compartment to represent a taxonomic group or feeding guild (e.g., all shrew species, avian seed eaters within a specified range of body weights) rather than individual species. In applications of TRIM.FaTE to date, the tertiary consumers generally have been represented by individual wildlife species compartments (e.g., a *red-tailed hawk* compartment type).

As described in Section 7 of the TRIM.FaTE Technical Support Document, Volume II (EPA 2002a), the transport algorithms for movement of chemical between the soil and soil detritivore compartment types (i.e., *earthworm*, *soil arthropod* compartment types) are based on equilibrium-partitioning models. The transport of chemical through bird and mammal compartment types is estimated using a bioenergetic model of chemical uptake, metabolic degradation, and excretion. Thus each wildlife compartment type includes several compartment-specific properties (e.g., body weight, number per meter squared, food ingestion rates, inhalation rates) and chemical- and compartment-specific properties (e.g., chemical assimilation efficiency, metabolic degradation rate, excretion rate). For each compartment type, the user must check that the values or equations included for these properties are appropriate for the species or group of species represented by the compartment type.

In specifying which animal compartments to assign to a given volume element, the user needs to add a spatial dimension to the conceptual model. In so doing, the user should not think of a volume element (or rather, the underlying parcel) as the boundaries of an animal's home range. In reality, vertebrates may move between parcels, but within the TRIM.FaTE modeling system, each biotic compartment is assigned to a single volume element (usually where the species would be expected to feed at least some of the time). For example, a compartment for a mammalian consumer group with a relatively small foraging range (e.g., shrews) would be assigned to the surface soil volume element from which they are expected to feed 100 percent of the time. On the other hand, a compartment for a consumer group with individual foraging ranges large enough to encompass several surface parcels (e.g., hawks or eagles) would be assigned to a volume element representing the home base (e.g., nest site), with links to prey compartments in more than one volume element. Thus, specifying trophic links among terrestrial compartments will include a spatial dimension, as described in Section 4.2 below.

4.2 Defining the Terrestrial and Semi-Aquatic Food Webs

In general, a key point to remember when developing the trophic links between animal compartments and compartments representing what they consume is that chemical mass is transported between and transformed within *compartments*, not volume elements. Therefore, it is important that the spatial links between compartments are properly configured, regardless of how animal compartment types are assigned to volume elements.

> **LINKS BETWEEN TERRESTRIAL AND AQUATIC ECOSYSTEMS**
>
> For semi-aquatic birds and mammals assigned to land (surface soil volume elements), the user must identify – for each volume element with which the species is associated – one or more *adjacent* water bodies from which the aquatic portions of the diet originate.
>
> Note that all land-based animals for which drinking water ingestion is modeled must be linked to one or more surface water bodies.

When wildlife compartments are added to a TRIM.FaTE scenario, the user must specify a diet and ensure that the components of the diet are also included in the scenario as biotic compartments. An animal's actual diet may be simplified for purposes of the TRIM.FaTE model. Each wildlife compartment added to a scenario should be accompanied by and linked to compartments from which they gain and lose chemical mass through trophic interactions (i.e., compartments must be included to account for key predator and prey dynamics). In some cases(e.g., deer in hunting areas), a dummy predator or predator sink compartment could be added to more realistically model the loss of chemical from that population to hunters, other predators, or scavengers.

The current TRIM.FaTE library contains a set of dietary uptake algorithms specific to common occurrences of predator-prey relationships among the existing animal compartment types. In specifying the diet for an animal compartment, the user will want to confirm the existence of algorithms to support any food-chain connection they make between biota. If a new compartment is added or renamed (e.g., to represent a site-specific trophic group), the user will need to ensure that algorithms are added or revised to reference the newly named compartment. If an algorithm does not exist, the user can create one based on other similar types of algorithms, if appropriate (see Module 4, Adding New Compartments, for information about adding algorithms). If the necessary

> **LINKS BETWEEN BIOTIC AND ABIOTIC COMPARTMENTS**
>
> All terrestrial biota in the current library, except for earthworms and arthropods, should be linked to an air compartment (i.e., animals via a link for breathing; plants via a link for exchange). The TRIM.FaTE scenario verification process currently does not perform this check.
>
> Smart Link may not make all the necessary links for biota in a scenario. For example, Smart Link does not make links between surface drinking water and terrestrial biota or links between fish-eating terrestrial animals and fish; these links need to be made manually by the user. Refer to Module 8, Links and Algorithms, for more information.

algorithm changes are not made, TRIM.FaTE will report them as errors during the verification step.

There are two TRIM.FaTE properties used in the current library to specify the diet of a bird or mammal compartment: (1) the *FractionDiet[food compartment]* (fraction of the diet that consists of a particular food compartment type) and (2) the *FractionSpecificcompartmentDiet* (fraction of that type of food that is obtained from different locations (i.e., volume elements)). Each property is described below.

- ***FractionDiet[food compartment]*** is an animal *compartment property* that specifies by mass fraction, on a wet-weight basis, the different components of the animal's diet. Food sources for a particular consumer are substituted for the "food compartment" value in brackets (e.g., *FractionDietMouse*). For example, if the short-tailed shrew diet consists of 60 percent earthworms (by wet weight), the value of the *FractionDietWorm* property for the shrew compartment would be set to 0.60. If this compartment property is assumed to be constant over space for a given scenario (e.g., the *FractionDietWorm* of all shrew compartments included in a scenario are the same), it can be most efficiently set in the library before adding the compartments to the scenario. If, alternatively, this property is to vary by location in a scenario, the values will need to be assigned to the compartments in the different volume elements in the scenario. Refer to Module 1 for more information on setting values of TRIM.FaTE properties.

- ***FractionSpecificcompartmentDiet*** is a *link property* that defines how much of a certain diet component fraction is provided to a consuming organism compartment via a specific link connecting the consumer compartment in the specified volume element (consumer location) to its prey organism compartment in the different specified volume element (prey location). In the default configuration, predators are assumed to consume 100 percent of a particular prey compartment from a single volume element (typically the one in which they are located); however, the user can change this property to accommodate scenario-specific conditions. This property, input as a unitless fraction, can be used to allow predators in one volume element to consume a given prey type from multiple volume elements (e.g., for a predator such as the bald eagle with a foraging range that might encompass many different terrestrial and aquatic parcels/volume elements in the user's scenario).

  As stated above, this property is a link property (i.e., it does not exist in the library). It is automatically created and given a value of 1.0 when the user runs "Verify" for their scenario. Consequently, if the user wants to specify that an animal consumes the same prey item from multiple volume elements, they could run "Verify" and then change the value on each affected link to reflect the desired proportion of that component of the animal's diet to be taken from that volume element. To accomplish this prior to running "Verify," the user would need to add this property to each affected link and assign it their desired non-1.0 value.

To assist the user in confirming designation of a full diet, the food chain leading to any animal compartment can be viewed (see text box at right). Additionally, during the "Verify" step that should be employed prior to running the model, the values of the *FractionDiet[food compartment]* and *FractionSpecific compartmentDiet* properties used by ingestion algorithms for each animal compartment are checked as follows. For a given animal compartment, the sum of all of the *FractionDiet[food compartment]* property values must equal 1.0. Additionally, for that given animal compartment (e.g., bald eagle), the sum of all of the *FractionSpecificcompartmentDiet* properties on links between it and prey compartments of the same type (e.g., mice associated with volume element A and mice associated with volume element B) must also equal 1.0. If either of these conditions are not true, an error will be returned informing the user of the consuming compartment and property for which the sum-to-1.0 check failed.[5] See the example presented in Table 1.

VIEWING A FOOD CHAIN/WEB IN TRIM.FaTE

The food web leading to any animal compartment (i.e., the "sink food web" for that animal) can be viewed in TRIM.FaTE. First, highlight a biotic compartment in the scenario. Then, go to the "View" pull-down menu and select the "Food Chain" option. A graphical representation of the sink food web for that compartment will appear in a new window.

4.3 Assigning Total Biomass Density and Biomass Densities Across Trophic Levels

In calculating and assigning the population and biomass densities of terrestrial animals, the user will need to consider the units required by TRIM.FaTE (e.g., the number of individuals per square meter, *#/m²*) compared with those reported in literature as well as any site-specific qualification of literature values. Published animal density values for similar habitats local to the modeling region will usually be preferred. The user may need to perform some calculations to convert the literature values to the units required by TRIM.FaTE. For example, population density relative to water body shoreline length may be the most common measure reported in the literature for semi-aquatic mammals, such as mink, and the user will need to convert that into an estimate of mink density per square meter of the adjacent land parcel (i.e., the surface soil volume element to which a mink compartment is assigned). After assigning population density values to each compartment of a given species/group compartment type, the user needs to check the appropriateness of the overall (or total) population or biomass density presumed for that species (or trophic level group) in the study area.

[5] Note that, as described in Module 8 (Links and Algorithms), SmartLink may create links that are not needed for a particular scenario. While these usually can be ignored as having no impact on model runs, if the user is utilizing the *FractionSpecificcompartmentDiet* property (i.e., setting it to other than 1), they should check for the existence of unneeded links involving the consumer and the food item that is being consumed from different locations.

Table 1
Example of Hypothetical Food Web and Corresponding Properties

Conceptual Component of Food Web	‣ Predator: Red-tailed hawk ‣ Food types consumed: black-capped chickadee (30% of diet), meadow vole (20% of diet), and mouse (50% of diet)
Spatial Assumptions (Scenario Food Web)	‣ The red-tailed hawk is located in volume element (VE) A. ‣ The black-capped chickadees consumed by this hawk are also located in VE A. ‣ The meadow voles consumed by this hawk are located in VE B. ‣ Mice consumed by this hawk are located in both VE's A and B. The hawk consumes 30% of its mouse diet from VE A and the other 70% from VE B.
TRIM.FaTE compartment properties for the red-tailed hawk These properties can be set in the library before creating a scenario, or in the scenario.	‣ *FractionDietChickadee* is set to 0.3. ‣ *FractionDietVole* is set to 0.2. ‣ *FractionDietMouse* is set to 0.5. ‣ Total sum of *FractionDiet* properties for the hawk is 1.0.
TRIM.FaTE link properties for the red-tailed hawk in VE A These properties are set in the scenario, either by importing a link properties file or directly by the user via the GUI.	‣ The *FractionSpecificcompartmentDiet* for the link between the hawk in A and the chickadee in A is set to 1.0. No other links to chickadee. ‣ The *FractionSpecificcompartmentDiet* for the link between the hawk in A and the meadow vole in B is set to 1.0. No other links to vole. ‣ The *FractionSpecificcompartmentDiet* for the link between the hawk in A and the mouse in A is set to 0.3. The *FractionSpecificcompartmentDiet* for the link between the hawk in A and the mouse in B is set to 0.7. The sum of *FractionSpecificcompartmentDiet* properties for all links between hawk and mouse compartments equals 1.0 as required.

It is up to the user to specify a reasonable distribution of biomass among trophic compartments in the terrestrial ecosystem. As described in the accompanying text box, a reasonable rule of thumb to use in the absence of appropriate whole ecosystem studies reported in the literature or local data might be that the standing biomass of a consumer organism not exceed 1/100 of the sum of the standing biomass of its food compartment(s). Note that this rule of thumb should hold true across all consumer and food compartments across all volume elements. So, after checking that the sum of the biomass in the food compartments are sufficient to support the consumer compartments, the user needs to check that the ratio of the sum of the biomass of all of the different consumers of a particular food compartment to the biomass of the food compartment does not exceed 1/100. This process of ensuring a reasonable standing biomass pyramid might require a few iterations. In summary, when setting the population densities for compartments in the terrestrial ecosystem, there are several conditions that the user should consider:

TERRESTRIAL BIOMASS PYRAMIDS

In north temperate deciduous forests, only a few (two to five) percent of the net primary productivity (NPP) of plants is consumed by herbivores, and less than one percent is assimilated by the herbivores (Hairston and Hairston 1993). More than 95 percent of the NPP passes into the detritus on the forest floor. The forest floor detritivores generally assimilate two to six percent of the NPP (Edwards et al. 1970). Thus, the ratio of the standing biomass of primary consumers to the biomass of primary producers in a north temperate deciduous forest is on the order of 3/100 to 7/100.

The ratio of the standing biomass of carnivores to their prey in many different types of terrestrial ecosystems recently has been estimated as roughly 1/100 (Carbone and Gittleman 2002).

Thus, it would appear that the standing biomass in successive trophic levels in these systems decreases by more than one and possibly two orders of magnitude.

(1) The total biomass of plants and detritivores in the soil (e.g., earthworms, soil arthropods) is a reasonable representation of the ecological capacity of the ecosystem being modeled;

(2) The total biomass of herbivores is a reasonable representation of the ecological capacity of the vegetation compartments being modeled;

(3) For other terrestrial animal compartment types that are included in the scenario, all supporting trophic compartments and links are also included; and

(4) The standing biomass pyramids that include those animal compartments should be reasonable (e.g., a ratio of predator to prey biomass of approximately 1:100).

Given that the ratio of biomass of consumer organisms to the biomass of their food sources in terrestrial ecosystems has been estimated to be around two orders of magnitude (see text box above), the influence of omitting species of primary, secondary, and tertiary consumers on the concentrations of chemical at different trophic levels in terrestrial ecosystems is believed to be less than in aquatic ecosystems.

4.4 Adding Clean/Contaminated Food Sources from Outside the Modeled Domain

There may be situations in which the user may want to implement a food source for an animal that is unaffected by the modeled chemical source. To do this, the user could add a new "clean" food compartment and an ingestion algorithm for the animal to ingest food from this new compartment. In addition, the user would create a new *FractionDiet[food compartment]* property and link between the new compartment and the animal to include the new compartment in the animal's diet.[6] Without an algorithm to move chemical mass from anywhere in the scenario into this new "clean" compartment, it would not contribute chemical mass to the consuming animal. Alternatively, the new food compartment could be assigned a constant or time-varying chemical concentration. See Section 1.6 of Module 12, Pointers for Setting Up a TRIM.FaTE Scenario, for information regarding specifying concentrations.

Situations in which adding food compartments that are external to the TRIM.FaTE modeling domain may be useful include modeling the occurrence of scavenging animals (e.g., raccoons) that may take a portion of their diet from human generated items, species with large home ranges, or species that feed in groups that roam beyond the domain boundaries (e.g., deer, great blue herons).

5. REVIEWING AND EVALUATING THE BIOTIC SYSTEMS

In this section, some additional suggestions are provided for ensuring that the relationships between the terrestrial and aquatic components of the model are properly integrated (Section 5.1) before the user assesses model performance for their application (Section 5.2).

5.1 Integrating the Aquatic and Terrestrial Ecosystems

One of the most complicated aspects of setting up biotic compartments in TRIM.FaTE is ensuring appropriate links and biomass relationships between the aquatic and terrestrial ecosystems. As mentioned earlier, it is very important to ensure that the "predation pressure" exerted on the aquatic compartments is reasonable. Thus, after assigning biomass to the biotic compartments, it is prudent to recheck the biomass ratios between the predators in the terrestrial ecosystem and the prey in the aquatic ecosystem.

Assuming the user has established realistic biomass densities in the aquatic systems, they will need to confirm that the terrestrial predator densities and *DietFraction[aquatic prey]* values achieve a reasonable predation pressure on the aquatic ecosystem. This will need to be confirmed for each surface water body modeled in the scenario. The user needs to consider all of the different wildlife compartments that obtain some or all of their diet from a given surface water volume element. Note that the scenario may have some fish compartments from a given surface water volume element linked to multiple wildlife compartments of the same type but in different parcels adjacent to the surface water. For example, the mink assigned to two surface

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[6] Rather than using the "Add" function to add the new compartment, an existing biotic compartment could be duplicated, with the duplicate then revised to be an "other food" compartment. Similarly, an existing ingestion algorithm for the consuming animal could be duplicated, and the duplicate revised to describe ingestion of the new "other food" compartment. See Module 4, Adding New Compartments, for information on adding compartments, algorithms, and properties to a TRIM.FaTE library.

soil volume elements, both adjacent to a single surface water volume element, might be modeled as consuming some of their prey from the same fish compartment(s) in that surface water body. In this example, the user must account for calculation of the predation by both mink compartments on the fish compartments in that surface water volume element.

If the predation pressure needs adjustment, predator or prey population densities, as well as the assignment of the various spatial predator-prey links, may need reconsideration. Considerations in identifying the compartment type(s) to adjust, as well as the amount by which adjustments may need to be made (in the case of population density), include the quality and local applicability of the available data used to establish the initial biomass densities.

5.2 Evaluating Sensitivity of Results to Trophic Structure and Biomass Distribution

Factors to consider in evaluating the implementation of a biological system in a TRIM.FaTE scenario include:

- Which biotic compartments are the most important given the goals of the application;
- Which links to those compartments might account for the highest chemical fluxes in and out of those compartments;
- The quality and local applicability of the input data on biomass densities, trophic relationships, and other compartment-specific input properties;
- Simplifying assumptions used; and
- The likely natural variability in those parameters.

A useful first step in the evaluation strategy could be a sensitivity analysis for the biotic compartment-specific input property values. Understanding the potential magnitude of natural variation in the values of those properties and possible correlations (relationships) between property values will help in constructing an appropriate sensitivity analysis. Property values that are highly uncertain need particular consideration. Those may include the compartment- and chemical-specific properties such as the rates of metabolic degradation. Additional manipulations to evaluate the performance of the model might include:

- Altering the relative distribution of biomass among trophic levels within the aquatic ecosystems, within the terrestrial ecosystem, and between the aquatic and terrestrial ecosystems;
- Removing or adding certain biotic compartment types (e.g., top predators or primary consumers), and
- Improving the representation of seasonal changes in animal population density and dietary composition (see Section 6).

6. SEASONAL FEATURES

TRIM.FaTE is a dynamic model that can incorporate seasonal changes in compartment characteristics and the fate and transport of chemical mass within the modeling domain. Two seasonal characteristics are available in the current TRIM.FaTE library: the seasonal presence of plant leaves (Section 6.1) and the transport of chemical between plants and the surface soil during litterfall (Section 6.2).

6.1 Seasonal Plant Availability

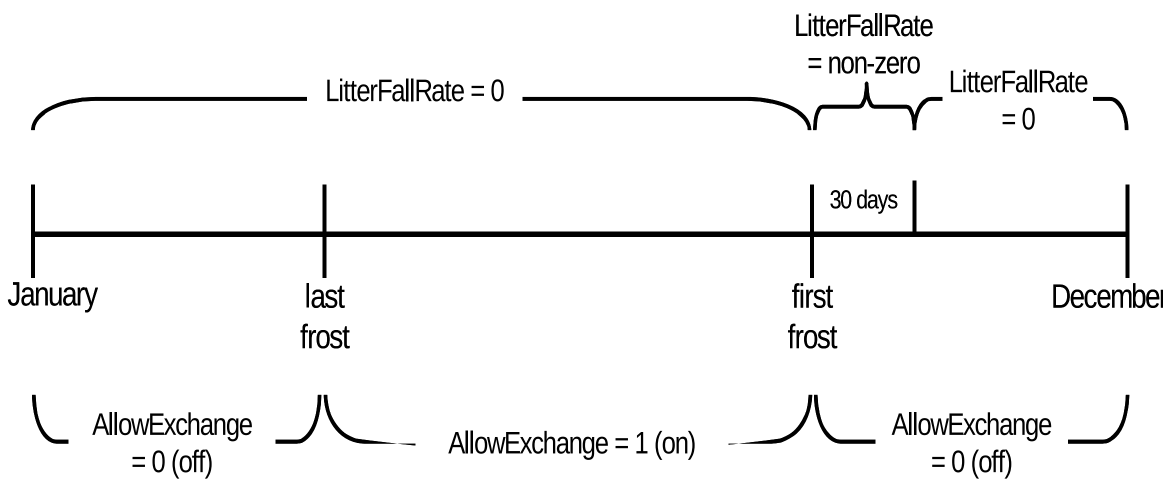
Seasonality, as it affects vegetation and consumption of vegetation by herbivores in TRIM.FaTE, is implemented primarily through the *AllowExchange* property. *AllowExchange* is set by the user to switch from 0 (off) to 1 (on) on a user-specified date (e.g., in the spring) and from 1 to 0 on a user-specified date (e.g., in the fall). Temporal variation in the value for *AllowExchange* permits (or excludes, during the "off-season") uptake and release of chemicals from soil and air by certain terrestrial vegetation types (e.g., deciduous plants, grasses/herbs, and agricultural plants) and consumption of this vegetation by herbivores. The on/off dates may be used to roughly correspond to growing season, which could be estimated by date of first/last "frost" (i.e., lowest temperature of the day ≤ 32 degrees F or 0 degrees C).

6.2 Litterfall

The current TRIM.FaTE library includes algorithms that transfer chemical mass from leaves and particles on leaves to soil as a simulation of leaves (or needles) falling off plants and the decay of grasses/herbs (e.g., at the end of the growing season) (see Section 7.2.7 of the TRIM.FaTE Technical Support Document, Volume 2 (EPA 2002b)). These algorithms reference a leaf compartment property, *LitterFallRate*, which can be set to a constant or a time-varying value, as suited to the application. In applications to date, this property has been set to a constant for coniferous forest (simulating a constant low rate of needle dropping) and an input data file has been used to vary the value for deciduous vegetation between 0 during the growing season (initiated with the date of last frost) and a non-zero constant for 30 days beginning with the date of first frost in the fall.

In setting the *LitterFallRate* values, attention should also be paid to the *AllowExchange* values. For example, during and/or after the dropping of deciduous leaves via the non-zero *LitterFallRate* value, it is appropriate that *AllowExchange* would be turned off (i.e., vegetation no longer takes up chemicals or is available for consumption by herbivores). Refer to the time line in Figure 2 for an example of how the values for *LitterFallRate* and *AllowExchange* could be varied temporally.

Figure 2
Example of Time Line for AllowExchange and Litterfall for Deciduous Vegetation



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APPENDIX A
CALCULATIONS OF AQUATIC BIOMASS TROPHIC PYRAMIDS

Appendix I-B (Biomass of Fish) of Volume I of the Evaluation of TRIM.FaTE (EPA 2002a) presents an example of the derivation of fish population densities across trophic levels in an aquatic ecosystem. Data from individual species in 19 central Ontario lakes were evaluated to construct the standing biomass pyramid for the aquatic ecosystems in the applications of TRIM.FaTE to date. After assigning fish species/age-groups to trophic levels, the analysis revealed the following distribution of biomass among the different fish trophic groups represented in TRIM.FaTE. Average biomass density (kg[fish wet weight]/m^2) of the secondary consumers in the benthic environment (fish that largely consume benthic invertebrates ($BF_{Secondary}$) was about 19E-04 and of largely tertiary consumers in the benthic environment (benthic fish that feed on other benthic fish, $BF_{Tertiary}$) was 2.1E-04, for a ratio of ($BF_{Teritary}$)/($BF_{Secondary}$) biomass density of 1/9. The average biomass density of the primary consumers in the water-column (i.e., planktivorous fish - $WCF_{Primary}$), and largely secondary ($WCF_{Secondary}$) and tertiary ($WCF_{Tertiary}$) consumer fish groups in the water-column environment were 16.5E-04, 5.85E-04, and 1.8E-04 (kg[fish wet weight]/m^2), respectively. Thus, the ratio of $WCF_{Tertiary}$/$WCF_{Secondary}$ biomass density was 1/3.25, and the ratio of $WCF_{Secondary}$/$WCF_{Primary}$ biomass density was 1/2.8. Note that the ratios of $WCF_{Tertiary}$/$WCF_{Secondary}$ and $WCF_{Secondary}$/$WCF_{Primary}$ biomass densities were much less than 1/10.