Narrative of Conceptual Ecological Models for Interior Least Terns And Piping Plovers on the Missouri River—DRAFT

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Introduction

The conceptual ecological models (CEMs) for piping plovers, and least terns on the Missouri River Mainstem System (MRMS), developed as part of the Effects Analysis, were created to:

- illustrate the general hydrological, physical, and ecological relationships that affect terns and plovers, from the underlying drivers to species performance;
- indicate relative importance and uncertainty of relationships within this system;
- connect current and proposed management actions to habitat and species responses, including the fundamental objectives of the Missouri River Recovery Program;
- help with the selection of means objectives for habitat and species management and show their relationships to fundamental objectives;
- provide a basis for formulating testable hypotheses regarding the effectiveness of management actions on species performance and other fundamental uncertainties;
- act as a framework for organizing information, identifying critical uncertainties, and identify research, monitoring, and evaluation needs;
- provide the conceptual basis for determining the necessary components for a numerical, predictive model. While the numerical model to be developed in the near term will not quantify every relationship in the CEM, the CEM includes the level of detail necessary to help make these decisions;
- illustrate and document reasoning involved in decisions about objectives, hypotheses, and models; and,
- support the adaptive management process as a working document that reflects new information and understanding of the system over time.

The CEMs were initially developed at workshops held in July 2013 held by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service and attended by biologists and river experts from state and federal agencies. Following the workshops, the model diagrams were cleaned up and shared for external review. Review comments were received by the effects analysis team in late November. The effects analysis team made a series of revisions to arrive at the current draft version of the CEM.

The structure of the CEM has some similarities to the causal network approach (e.g. Niemeijer and de Groot, 2008), in that the model tracks the influence of broad drivers through to the response of the focal species. The causal influences move from left to right through the diagram; though there may be feedbacks from responses back to drivers and controlling factors, they are not graphically represented in this type of conceptual model. They may be added as needed for developing management action hypotheses. The CEM also includes a demographic stage-transition model for the tern and plover populations. Model components are grouped into six categories:

- **Drivers** are the underlying factors that determine much of the dynamics of the system, but are not themselves determining physical or ecological responses. These include social, political and economic factors, basin runoff, and reservoir operations rules.
- **Controlling factors** are environmental conditions that drive ecosystem structure and function (Diefenderfer et al. 2009). These environmental conditions link drivers to physical

responses. In this case, controlling factors include dam releases, tributary discharge and sediment supply. The effects of controlling factors on physical and ecological responses may be positive or negative, depending on whether they deviate from the natural range to which the system has adapted. When these factors are out of normal bounds (e.g. large changes to the magnitude or timing of flows compared to the natural hydrograph, such as a drought or the loss of a natural flow pulse), controlling factors may act as stressors or pressures as often used in causal network models.

- **Physical responses** are the hydrological and geomorphological responses to controlling factors, creating the conditions that are directly experienced by terns and plovers on the Missouri River. These include water level in the river and reservoirs and channel width and complexity during the time period when birds are nesting.
- **Ecological responses** include habitat area, species behavior (nest elevation and density, agonistic behavior, immigration and emigration) and interactions with other species (predation.) As the area suitable habitat is determined by the species' needs, preferences, and behavior, it is considered an ecological response, but it also has causal influence on the ecological responses by the species themselves.
- **Species performance** includes the life stages of the birds, from egg to adult, as well as the transitions (survival and egg production) between these stages. The CEM illustrates the effects of ecological responses on the populations by their effects on the transitions between life stages; however the fundamental objectives include the state of the bird population in terms of population size.
- **Management actions** are grouped into three categories that affect the system at different levels of the conceptual model: actions that affect river flow (controlling factors), actions that modify habitat (ecological responses/habitat) and actions that directly intervene with the population or biotic interactions (ecological responses or species performance).

The level of detail included in the model was driven by the CEM objectives listed above. The intended use of the CEM requires enough detail for the formulation of hypotheses about the effects of management actions and, when needed, testable intermediate hypotheses. A certain level of mechanistic detail was also desired in order to relate research findings to relationships in the CEM and to determine what elements are necessary in a numerical model of habitat and population dynamics. Beyond those requirements, simplifications were made when possible to limit the overall complexity of the diagrams and improve readability. More detail about hydrological and geomorphological factors may be provided at a later date as necessary for modeling the effects of management actions.

The CEM will serve as the guide for the development of numerical models in the Effects Analysis. Decisions about which components to include and whether to include them explicitly or implicitly (e.g. combined with other factors) will depend on the information available and the level of mechanistic detail necessary to determine the effects of management actions.

These relationship classifications are preliminary and subject to review and revision as the Effects Analysis is carried out. In some cases, the type of relationship is conditional upon the current state of the system and may be more or less important or certain under different conditions. Representing this

information in a single diagram is difficult, but may be significant in hypothesis development and testing. There are also relationships that may be well understood but hard to predict in the future. Other relationships may be uncertain because of the lack of information about the process but be more predictable if that information were known and thus may be key areas for future research. These distinctions will be further developed as needed during hypothesis development and numerical model development.

The general model as described below represents the "business-as-usual" scenario without the implementation of proposed management actions. The section on Management Actions describes the hypothesized pathways of the effects of current and potential management actions on species performance. Note that the implementation of the management actions would likely change the strength and certainty of particular model relationships; those changes will be explored and illustrated during hypothesis development. As management actions are implemented with the adaptive management program, the understanding of these relationships can improve through research, monitoring and evaluation.

Note: the following is a draft overview narrative of the processes illustrated in the conceptual model diagrams. It does not yet include the references being reviewed in the literature survey currently underway. However, a list of those references is included at the end of this document.

Drivers

Social, political, and economic factors have determined the Authorized Purposes of the Missouri River Mainstem System (MRMS) which include managing the river for flood control, hydropower, navigation, water use, recreation, and fish and wildlife. These factors also constrain future changes to system operation and are a source of uncertainty about future management.

Basin runoff includes snowmelt and rain entering this MRMS through tributaries and direct runoff into the river and reservoirs. The amount of water entering the system affects the range of reservoir operations possible in a given year, including the ability to meet specific flow targets. While water management under particular conditions is established in the Master Manual, runoff in specific future years and the overall stationarity of the system (whether patterns of runoff including frequency of droughts and floods are consistent over time) are highly uncertain.

The timing, duration, magnitude, and frequency of flows released by MRMS reservoirs are specified in the **Master Manual rules for reservoirs operations**. Based upon runoff conditions, the Master Manual determines the releases throughout the system through the course of the year, including seasonal release patterns in order to meet requirements for the authorized purposes.

Controlling Factors

Dam releases from May into August are determined by reservoir storage and operation rules and strongly affect the reservoir levels and river stages during the time of year when terns and plovers are

nesting. Higher releases increase water levels in the river below the dams. The effects of releases on reservoir levels depends upon the balance of releases for dams above a particular reservoir as well as the reservoir's own dam. Higher releases also increase sediment transport including the erosion and deposition of sandbars.

Dam releases from September through April are also determined by reservoir storage and operation rules. They do not directly affect the river and reservoir levels experienced by nesting birds, but transport sediment through erosion and deposition.

Tributary discharge adds to river stage below dams. As tributaries are not managed under the Master Manual, their outflows may or may not mirror trends in the mainstem dam releases which at times are driven by geographically distant runoff rather than local conditions. Tributary influence on river stage varies, and tends to be less predictable than reservoir releases on unmanaged tributaries.

Channel form includes the depth and width of the channel as well as its sinuosity. Channel form affects river stage as well as the likelihood and type of sediment transport at particular locations, with increased sinuosity increasing erosion and deposition along the outside and inside of bends, respectively.

Sediment supply (from the river bed and banks) affects the amount of sediment transported and, in part, the ability of sandbars to form in appropriate locations. The supply of sediment in the MRMS has been greatly reduced by the dams. Sediment settles in reservoirs rather than being carried downstream to settle in the river channel, thus limiting potential deposition.

Physical Responses

Nesting season reservoir levels are determined by dam releases (for the reservoir itself and from upstream reservoirs) and affect how much nesting and foraging habitat is available on the reservoir. Decreasing reservoir levels expose unvegetated substrate along reservoir shorelines which can be used for nesting. If reservoir levels are stable, vegetation growth on the exposed substrate renders habitat unsuitable over time. Increasing reservoir levels likewise reduce the amount of nesting habitat on reservoirs through inundation. Reservoir levels also determine where birds, primarily plovers, site their nests. Plovers tend to nest near the current water level such that sufficient increases in levels inundates nests and reduces nest success during the season.

Nesting season river stage is determined by dam releases, with contributions from tributary discharge in some parts of the river. River stage determines how much sandbar nesting/brooding and plover foraging habitat is exposed, with increases in river stage reducing the area of both types of habitat. River stage at the time birds are selecting nest sites may influence where birds locate their nests, thus affecting their resulting risk of inundation. Higher river stages also increase channel width (if banks are not vertical) and affects the complexity of sandbar habitat including edge-area ratios and connectivity.

Sediment transport is determined by river flows through the year (dam releases and tributary discharge), the supply of sediment and the channel form. The extent of erosion and deposition, and the

elevations where erosion and deposition occur, increases with increasing flows. Erosion and deposition then affect the width of the channel and the morphology of sandbars.

Channel width is determined by overall channel form, sediment transport (erosion of banks or deposition of floodplain sand), and the current river stage. It can affect the amount and perceived quality of nesting and foraging habitat, with wider channels potentially increases area of habitat and habitat quality.

Sandbar morphology and complexity includes elements such as sandbar elevation and shape (e.g. beaches vs. cutbanks), connectivity to the floodplain and other sandbars, and edge-area ratios. These factors determine how much of the sandbar is suitable for nesting and foraging, including absolute areas, access to wet sand foraging habitat from dry sand nesting habitat, accessibility to non-avian predators, etc. Morphology and complexity is determined by river stage, which can affect whether sandbars are connected to each other and the floodplain, and sediment transport which directly shapes sandbars.

Ecological Responses (Plovers)

Suitable nesting and brooding habitat for plovers consists of sparsely vegetated dry sand with access to foraging habitat, both on reservoirs and river reaches. The amount available depends on the river stage or reservoir level during the nesting season, the sandbar complexity and morphology, and to some extent the width of the channel. Habitat area affects nest density for a given population size, and to a small amount, immigration and emigration to and from the river and among segments of the river.

Foraging habitat for plovers consists of sparsely vegetated wet sand along sandbars and reservoirs. The amount available depends on the river stage or reservoir level during the nesting season, and the channel width and sandbar complexity. Foraging habitat availability determines nest density for a given population size, as plovers must select sites with access to sufficient foraging habitat for their chicks. This model assumes that if foraging habitat is present, sufficient vertebrate prey will be available.

Plover **nest elevation** is determined in part by reservoir levels and river stage as plovers choose sites with proximity to wet sand foraging habitat. The combination of nest elevation and water levels during the nesting period determines inundation risk and consequently affects the survival of eggs to chicks.

Nest density is a function of the area of nesting habitat available and the size of the population. Plover nest density is also determined by the availability of foraging habitat, as plovers select sites with direct access to foraging habitat and thus are unlikely to use areas of dry sand not adjacent to wet sand. High nest densities can lead to increased predation. Increases in nest density can also lead to increases in agonistic behavior as crowding leads to territorial behavior and aggression towards chicks from other broods.

Predation reduces survival of eggs to chicks and survival of chicks to fledglings, with a much smaller impact on the survival of more mobile and experienced adults. Predation has been observed to be more

significant when nest densities are higher, and is also affected by nest location, e.g. whether or not nests are on floodplain-connected habitat or separated by the river channel, or near gallery forest.

Agonistic behavior includes aggressive interactions towards chicks, driven by competition for foraging habitat, and is thought to have a minor impact on survival of chicks to fledglings.

Immigration and emigration rates are relatively low for plovers, as they tend to have high site fidelity and banding studies show limited movement of plovers between larger areas between nesting seasons. Such dispersal, when it does occur, affects the number of adults in a particular location.

Species Performance (Plovers)

The response of the species to the factors described above can be separated into effects on the transitions between key life stages: **eggs, chicks, fledglings**, and **adults**. The survival of eggs to chicks and chicks to fledglings takes place entirely on the MRMS, while the transition from fledgling to adult and the majority of the adult life, and consequently survival, takes place on wintering grounds away from the MRMS. Plover population dynamics are most sensitive to adult survival. However, because of their shorter life span, productivity is more important to plovers than to terns.

Survival from egg to chick is affected by nest inundation from rising water levels and by predation, with predation effects mediated by nest density and nest location.

Survival from chick to fledgling is similarly affected by predation, to a small extent by agonistic behavior, and most of all by foraging habitat area and their consequent ability to find food.

Adult survival during the nesting season may be reduced by predation, but the increased mobility and experience of adults reduces their risk.

The **number of adults** in a given area is affected by immigration and emigration, adult survival during the winter, and the arrival of first-year breeders that fledged the prior year.

Ecological Responses (Terns)

Suitable nesting and brooding habitat for terns consists of sparsely vegetated dry sand, primarily on river reaches, with limited use of habitat in reservoirs (typically sandbars exposed in upper portions of reservoirs when reservoir levels are low). The amount available depends on the river stage during the nesting season, channel width and sandbar complexity. Habitat area affects nest density for a given population size and immigration and emigration to and from the river and within areas of the river.

Foraging habitat for terns consists of shallow water. The amount available depends on the river stage or reservoir level during the nesting season, channel width and complexity. As terns can travel considerable distances to forage, local availability of foraging habitat does not have a strong effect on nest density.

As terns do not need to choose nest sites with immediate proximity to foraging habitat, **nest placement** is not as likely to be at lower elevations with higher risk of inundation as it is for plovers. However, if the

only available habitat is near the water level during the incubation period, nest locations can determine inundation risk and thus the survival of eggs to chicks.

Nest density is a function of the area of nesting habitat available and the size of the population. As a colonial species, tern productivity is not directly reduced by increases in nest density. However, high nest densities can lead to increased predation.

Predation reduces the survival of eggs to chicks and survival of chicks to fledglings, with a much smaller impact on the survival of adults. Predation has been observed to be a more significant factor when nest densities are very high, and is also affected by nest location, e.g. whether or not nests are on floodplain-connected habitat or within the channel.

Immigration and emigration rates are driven by habitat availability and quality. Terns have been observed to disperse to find suitable habitat to a greater extent than plovers. Such dispersal affects the number of adults in a particular location.

Species Performance (Terns)

The response of the species to the factors described above can be separated into effects on the transitions between key life stages: **eggs, chicks, fledglings,** and **adults**. The survival of eggs to chicks and chicks to fledglings takes place entirely on the MRMS, while the transition from fledgling to adult and the majority of the adult life, and consequently survival, takes place on wintering grounds away from the MRMS. Terns generally do not return to breed until their second or third year. Tern population dynamics are most sensitive to adult survival. Because of their longer life span, tern populations are less dependent on productivity for their survival than plover populations are.

Survival from egg to chick is affected by nest inundation by rising water levels and predation, with predation effects likely mediated by nest density and nest location.

Survival from chick to fledgling is similarly affected by predation as well as the ability of the adults to find sufficient food.

Adult survival during the nesting season may be reduced by predation, but the increased mobility and experience of adults reduces their risk.

The **number of adults** in a given area is affected by immigration and emigration, adult survival during the winter, and the arrival of first-year breeders that fledged the prior year.

Management Actions

There are broadly three ways in which management actions or the MRMS affect piping plovers and least terns: through flow modifications, through habitat creation or modification, and through direct intervention with ecological responses and species performance (e.g. predator control). Modifications to flow and habitat all aim to increase habitat area through various mechanisms under the common hypothesis that increasing habitat area will improve species performance. Direct interventions do not

affect habitat area but rather seek to mitigate the effects of stresses resulting from habitat limitation, hydrological alteration or human activity by directly protecting the bird population.

The following sections describe the hypothesized pathways and intended effects of each management action on tern and plover species performance.

Flow modifications

Fall flow releases are designed to increase dam releases while terns and plovers are not present to transport and deposit sediment, creating new sandbars and increasing the area and complexity of existing sandbars. Increases in sandbar area will then reduce nest density, improve foraging area, reduce predation, and consequently improve nesting success, chick survival, and overall population growth. Tern and plover population dynamics following high flows in 1997 and 2011 indicate that sufficiently high flows produce population increases in subsequent years, but the hydrological and socio-political conditions under which sufficient flows could be employed as a management action are highly uncertain. Sediment supply may become limiting in the long term.

Spring rise flow pulses of sufficient intensity and duration for habitat conditioning are proposed as a means of conditioning habitat by scouring vegetation and depositing new sand on existing sandbars. The resulting increases in area are hypothesized to follow similar mechanisms as with habitat forming flows; however improvements to sandbar area and quality would likely be less. The ability to conduct spring flow pulses of sufficient magnitude and duration to positively affect nesting habitat within current management constraints is highly uncertain.

Several types of **flow modifications to reduce take** have already been already used. These include short-duration increased releases from Gavins Point early in the nesting season to encourage birds to nest at higher elevations and reduce potential take from inundation later in the season. Flow management to limit take after nests are established, by holding flows steady, is also implemented when possible. These actions primarily work through the relationship of nest elevation to river stage to reduce nest inundation. Steady flows during the nesting season may also affect overall habitat area.

Habitat modifications

Sandbar construction creates new sandbars mechanically by placing and shaping dredge material. As with flow-based habitat creation, sandbar creation increases sandbar area which then reduces nest density, improves forage quality, reduces predation, and consequently improves nesting success, chick survival, and population growth. However, effects on the population are typically on a smaller, more local scale. Successful nesting and chick-rearing has occurred on constructed sandbars. In years with low habitat availability constructed sandbars have hosted a significant portion of tern and plover populations and productivity. The resulting high population and nest density, however, can reduce productivity through predation. Ecological traps can also result if only a few constructed sandbars support large portions of the population, rendering them vulnerable to predation and localized disturbances such as storms or human activity. The costs and logistical constraints of sandbar construction reduce the feasibility of large-scale implementation.

Vegetation management is designed to improve the habitat quality of existing sandbars and prolong the useful life of sandbar habitat by removing vegetation that deters birds from nesting and provides cover for predators. The resulting increase in suitable habitat area increases would then reduce nest density, improve forage quality, reduce predation, and consequently improve nesting success, chick survival, and overall productivity. The effectiveness of vegetation removal has not yet been demonstrated. While vegetation removal is not as costly as sandbar construction, there are still costs and logistical considerations that will affect the extent of potential implementation.

Species Protection

Predation management includes multiple techniques, including nest caging (for plovers) and predator removal. All are directed at reducing predation and thus increasing survival of eggs to chicks and chicks to fledglings. Predation management is a greater focus (and more practical) when habitat area is limited and predation more intense. Successful predator removal requires observation of, and access to, a predator in order to remove it and consequent improvements are difficult to measure, especially if removed predators are quickly replaced. Nest caging protects eggs but is less likely to protect chicks or adults; in some cases predators have been observed to use cages as a cue to find nests and therefore may increase predation on chicks or adults.

Nest relocation has been used to protect nests from inundation by placing them at higher elevations when river stage is expected to increase.

Human restriction measures include signs and rope barriers to deter people from accessing areas used for nesting and thus to reduce direct mortality of eggs and chicks to trampling, ATV's, dogs, etc. or to sublethal effects to stressed birds that may eventually reduce survival.

Responses to External Reviews

Following initial development during workshops in July 2013, an earlier version of these conceptual models was shared online for external review. The review comments that were specifically about the content and structure of the CEMs (as opposed to species objectives or comments about the overall effects analysis or adaptive management process) fell into three categories that we have responded to as follows:

1. Comments about completeness of references:

   Response: We will be incorporating the effects analysis literature review into the CEM and will use suggested references. If information from literature supports revisions to CEM relationships these will also be incorporated.
2. Comments about level of detail about dam operations and hydrology:

   Response: We have made some refinements to the hydrological controlling factors. The the hydrology/geomorphology team will also be developing conceptual model components including the level of detail needed for those numerical models.
3. Comments about specific components:

Response: We used suggestions from comments that were still relevant after other revisions were made, e.g. incorporating social/political/economic drivers. Some other suggestions addressed components that were already being revised.

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The following references are included in the ongoing literature review as of 1/7/14 and will be incorporated into the CEM as applicable. The references are categorized into themes that include most of the ecological response and species performance categories currently in the CEM, though the organization is somewhat different.

Plovers

Reproductive Success

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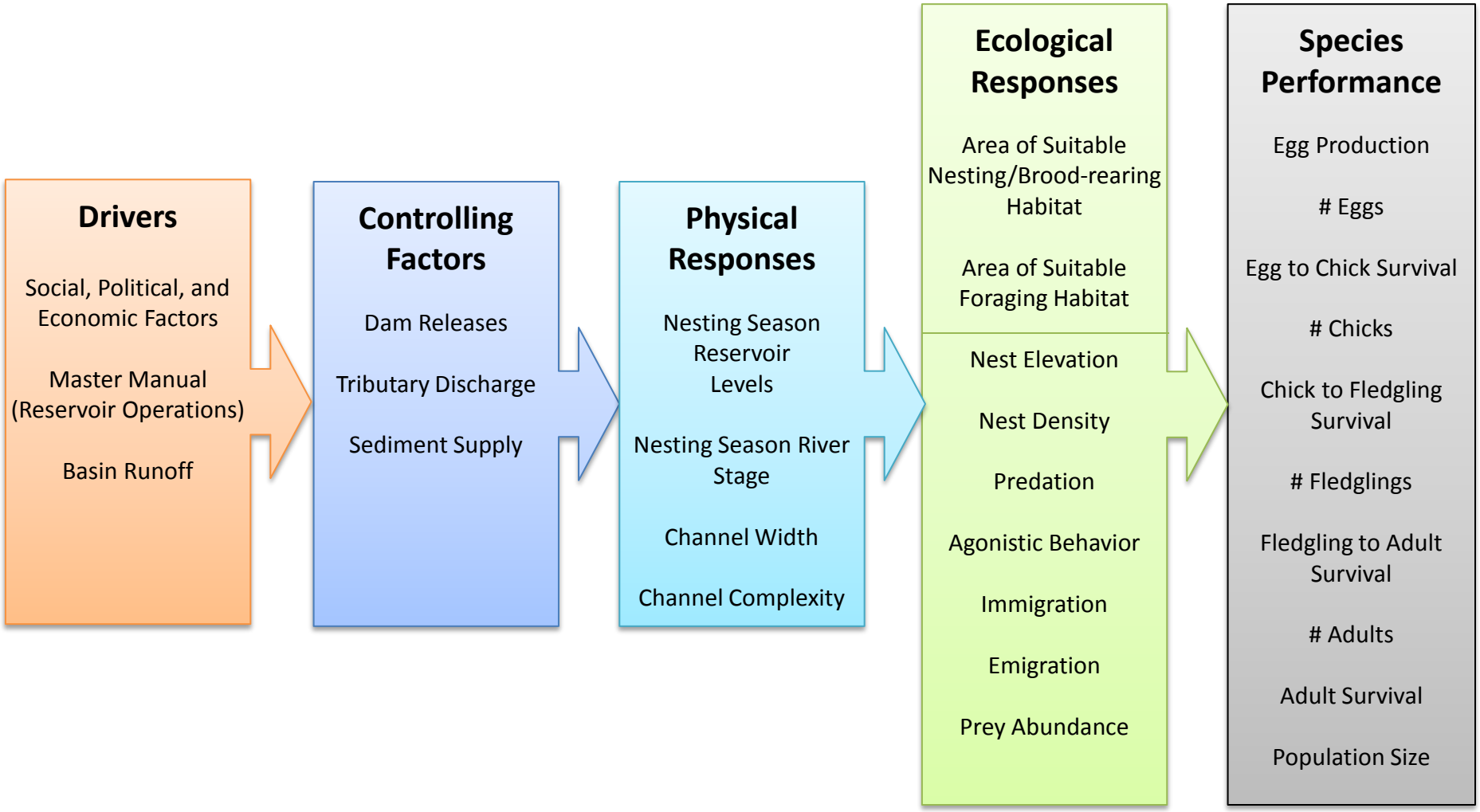
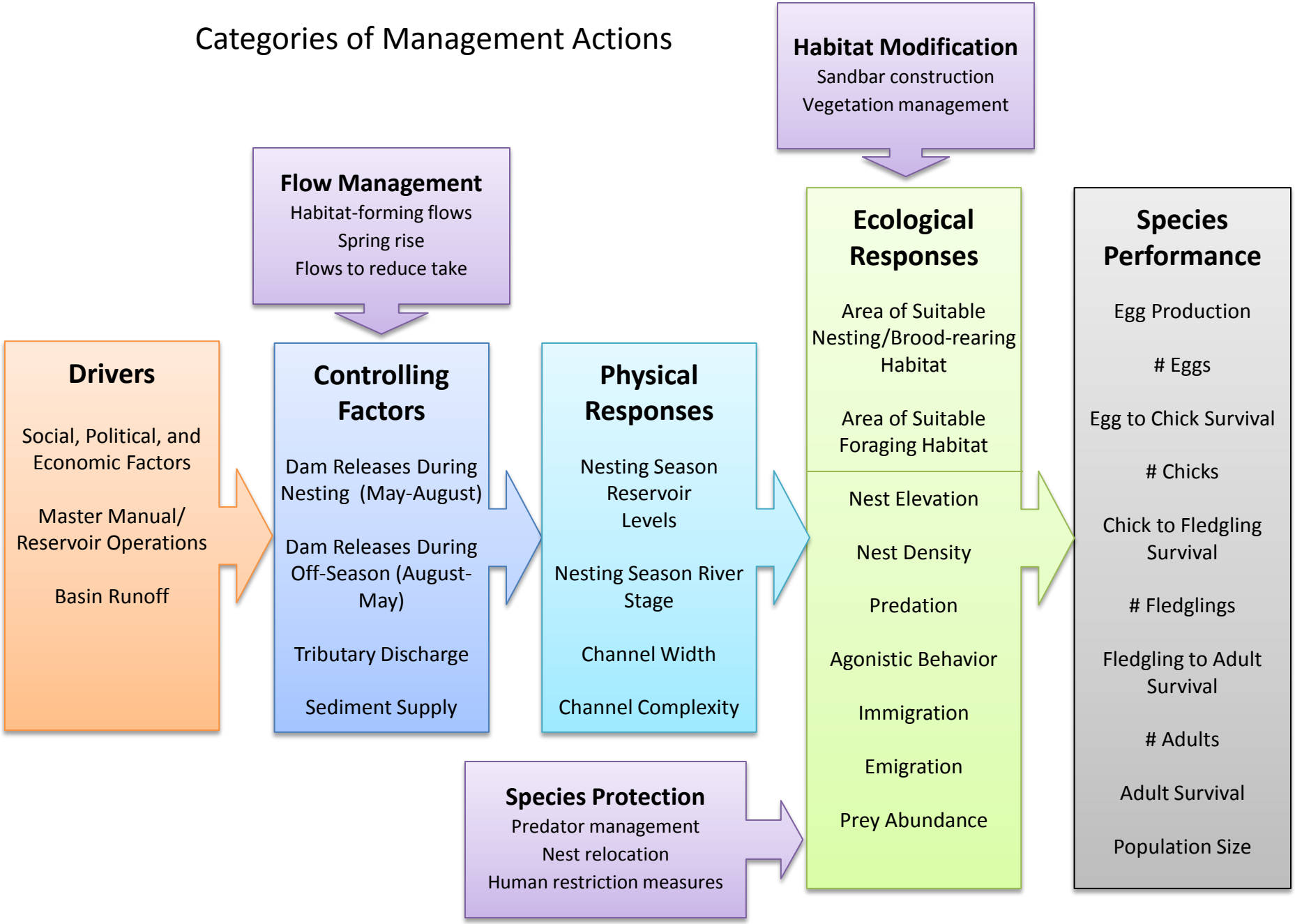
Conceptual Model Overview

Overview of Piping Plover and Least Tern Ecological Effects Model



Categories of Management Actions



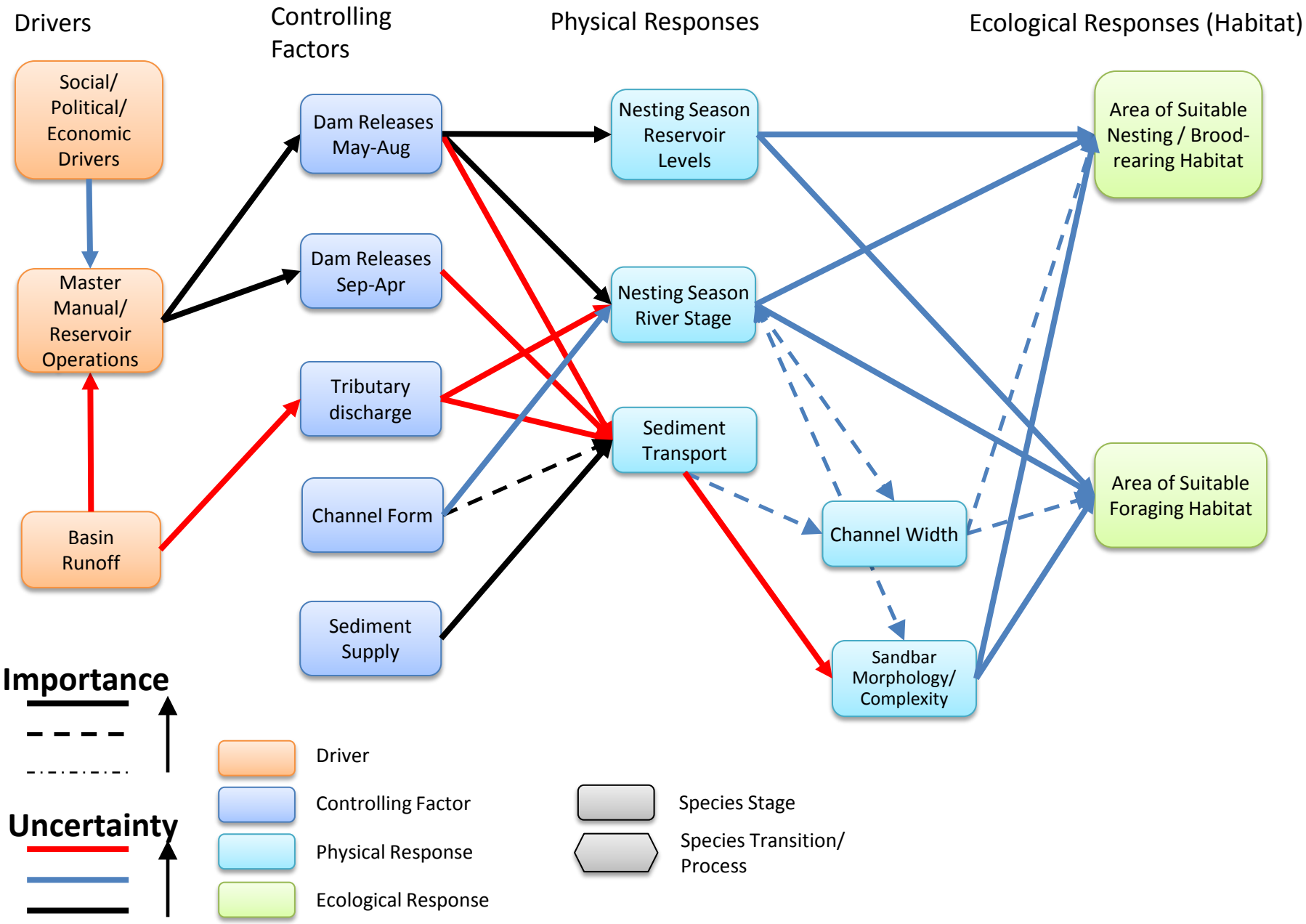
Detailed Conceptual Model

The model diagrams are divided into two slides per species (Drivers → Habitat; Habitat → Species Performance) to improve readability

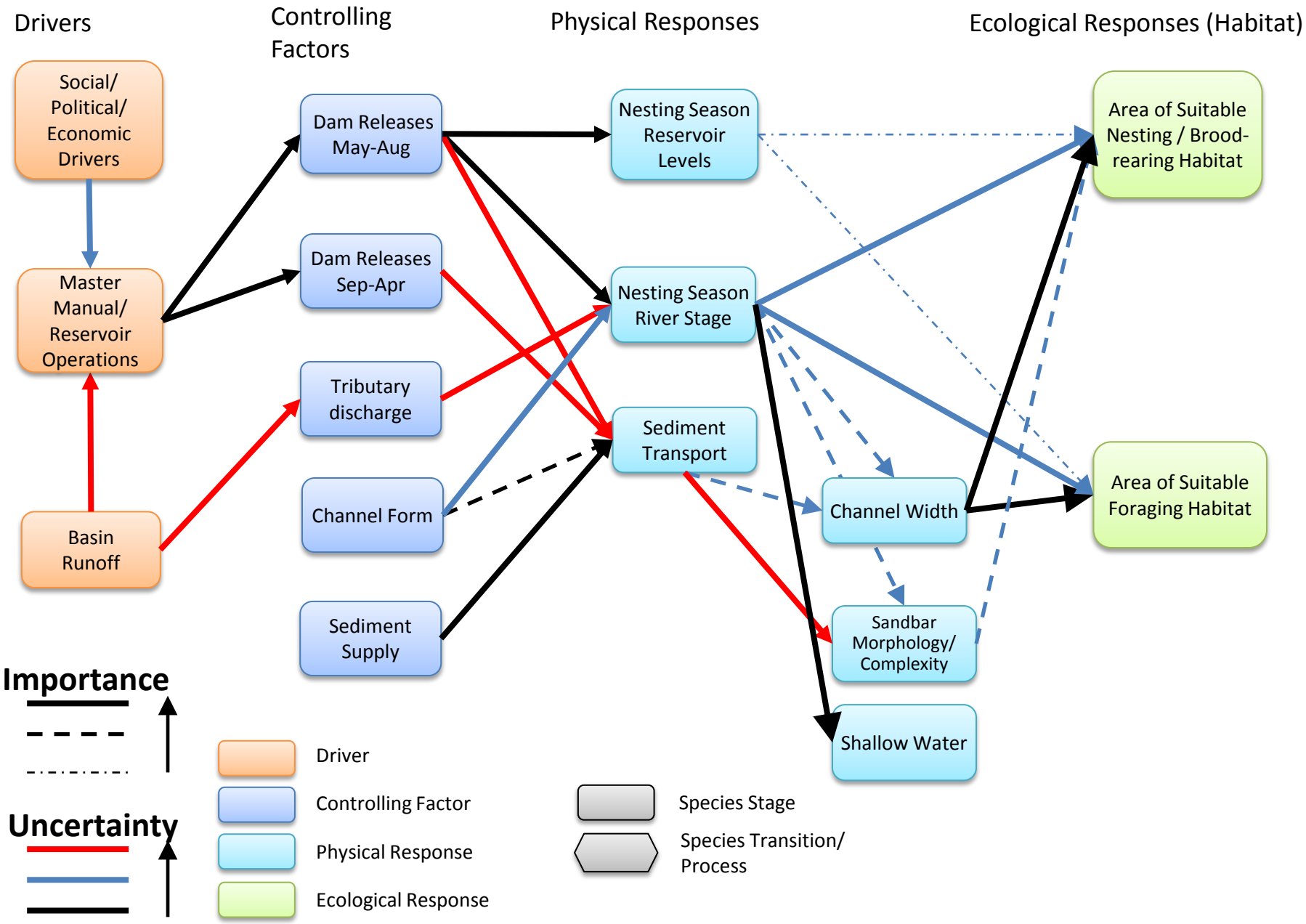
The type of arrow indicates the estimated importance of the relationship. The color of the arrow indicates the estimated uncertainty.

These diagrams illustrate the “business as usual” system, without the potential management actions.

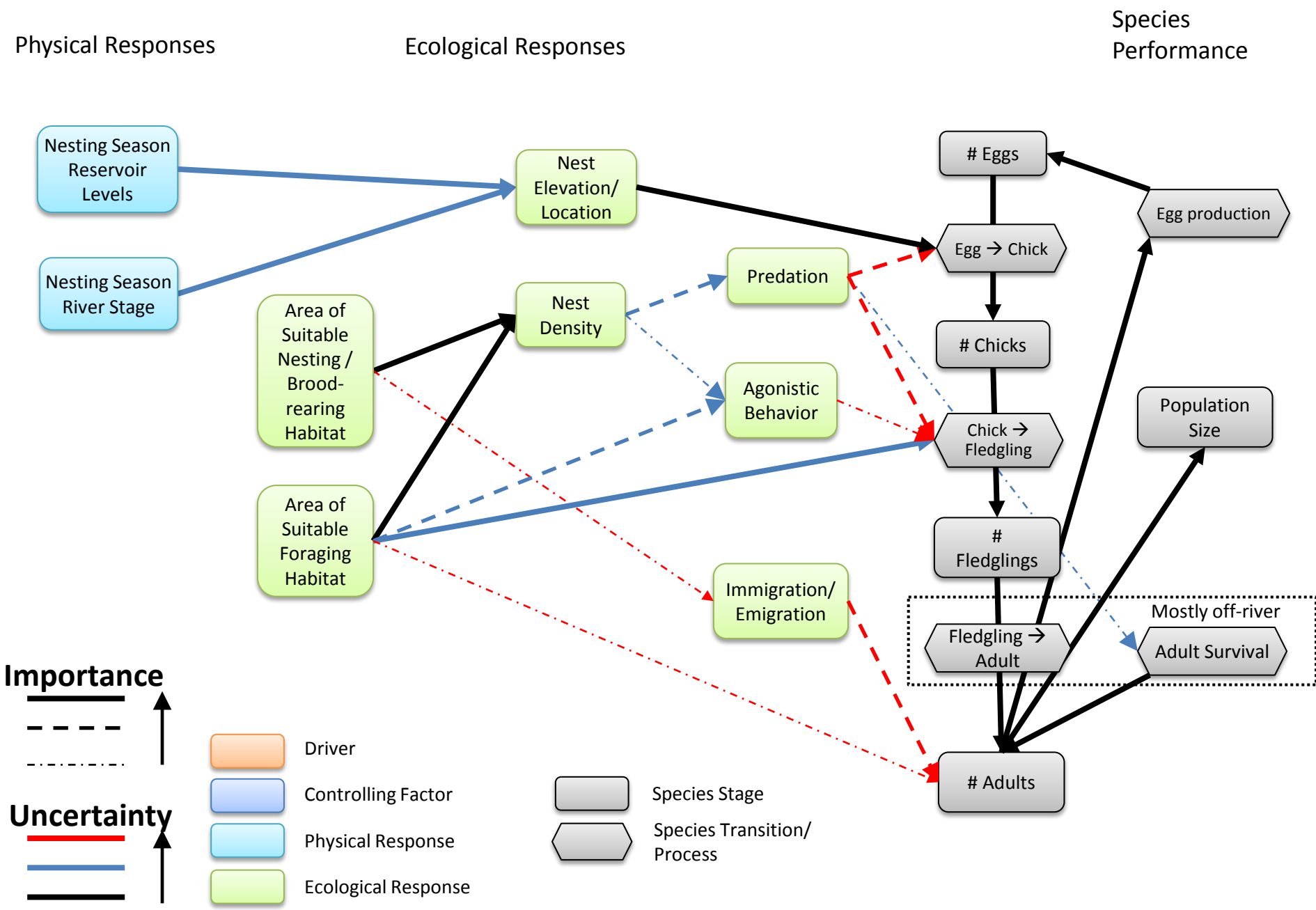
Piping Plover Ecological Effects Model: Drivers → Habitat



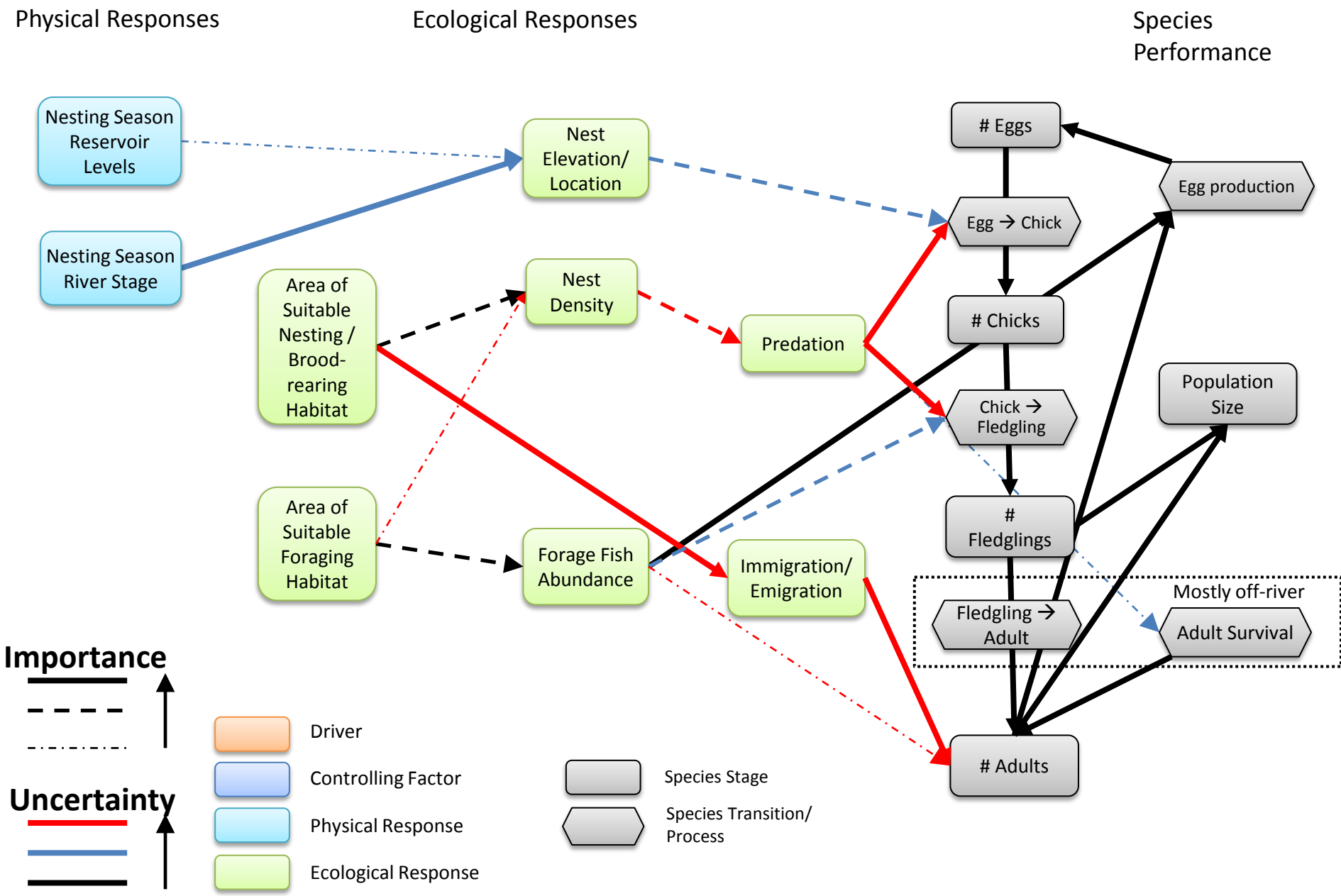
Least Tern Ecological Effects Model: Drivers → Habitat



Piping Plover Ecological Effects Model: Habitat → Species Performance



Least Tern Ecological Effects Model : Habitat → Species Performance

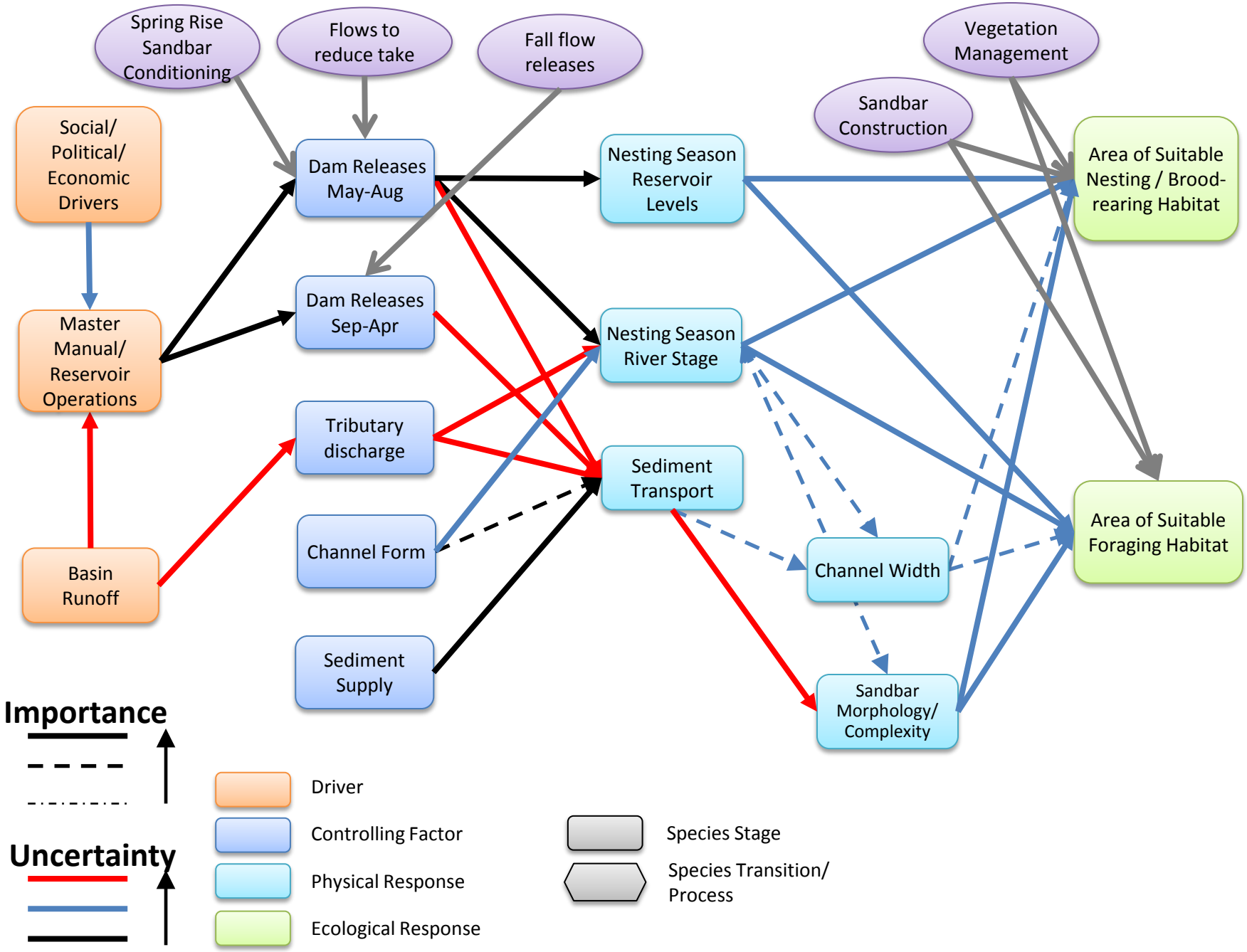


Detailed Conceptual Model with Management Actions

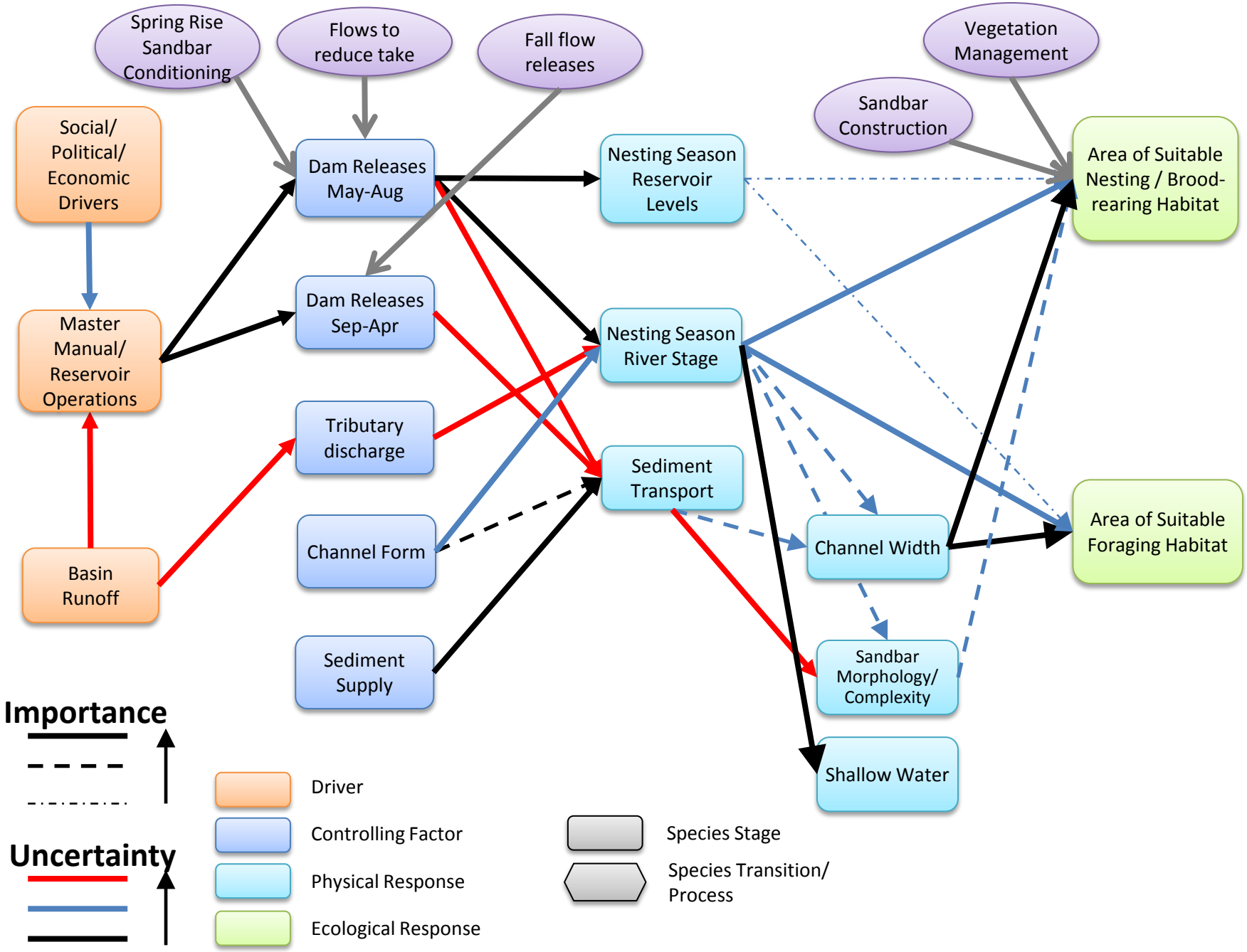
These diagrams illustrate the management actions according to the model component they directly affect.

They do not illustrate the changes that would occur to relationships (importance and uncertainty) if the management actions were implemented, as that will require separate diagrams for each management action.

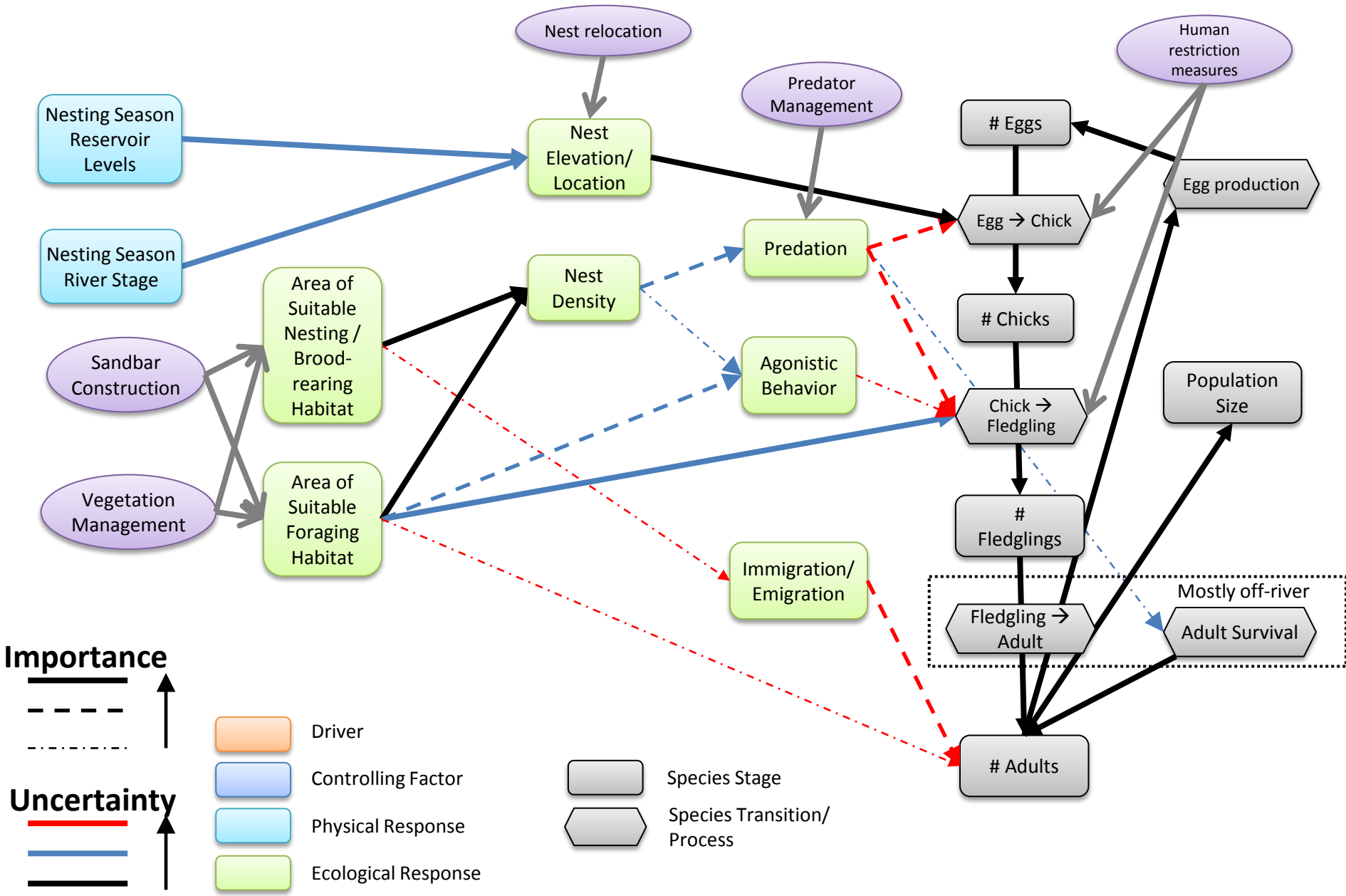
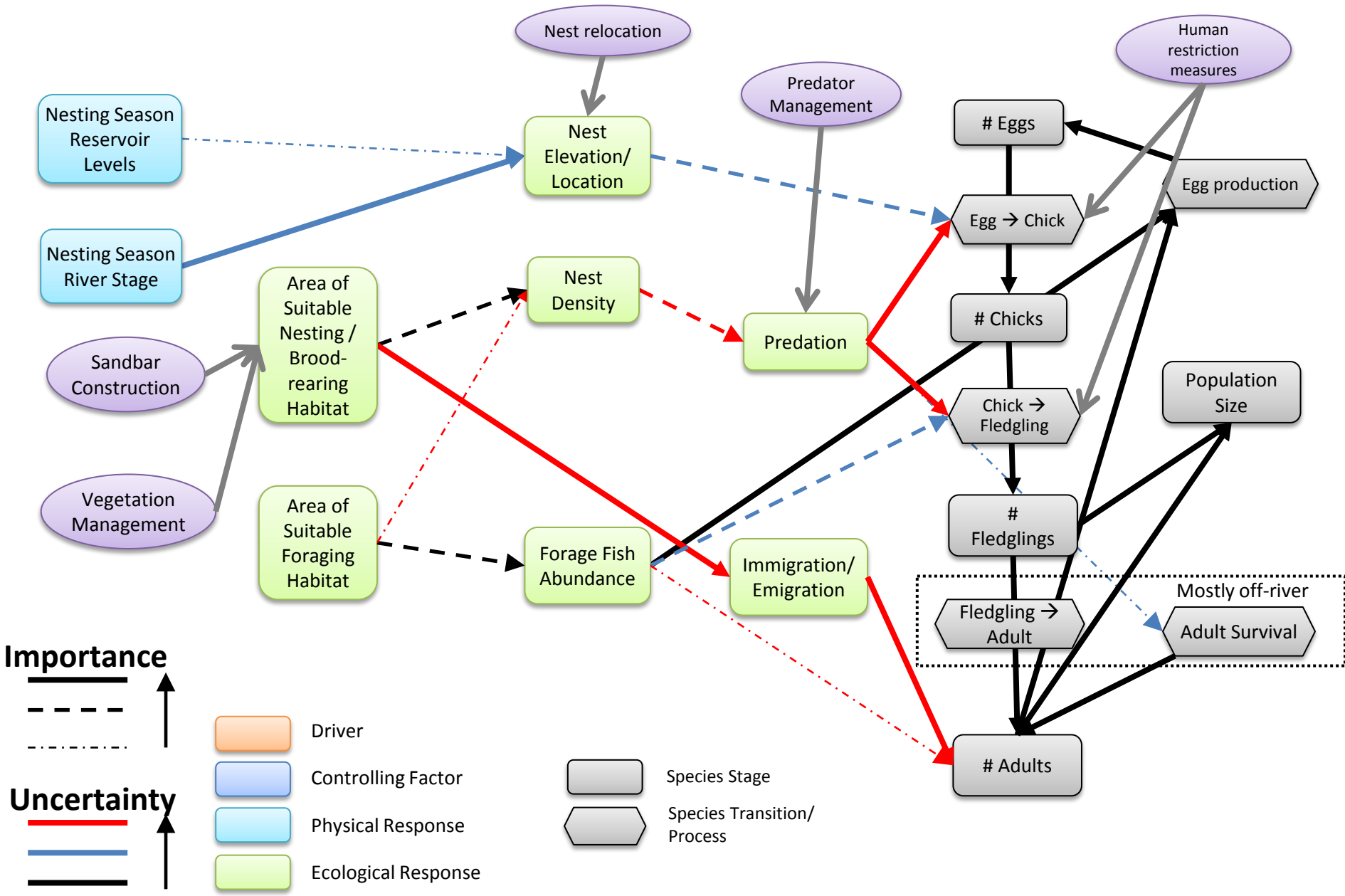
Piping Plover Ecological Effects Model: Drivers → Habitat



Least Tern Ecological Effects Model: Drivers → Habitat



Piping Plover Ecological Effects Model: Habitat → Species Performance



Least Tern Ecological Effects Model : Habitat → Species Performance