Supplementary Information

Metabolic theory predicts whole-ecosystem properties

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Materials and Methods

1. Proof of Equation 1 (main text)

Here we show that the average residence time of carbon molecules within an ecosystem at equilibrium is proportional to its total biomass divided by *GPP*. We assume that *GPP* is measured by the number (P) of carbon molecules entering the system every second, and that total biomass is measured as the total number (B) of carbon molecules in the ecosystem. We work in discrete time in seconds though the proof can be made general.

Of the P molecules entering the system every second, let the proportion staying in the system for time t and then leaving be p_τ, for τ = 1, 2, 3, ... T seconds. The number of molecules in the system that entered 1 s ago and stay for 1 s or more is $P(p_1 + p_2 + p_3 + ... + p_\tau + ... + p_T)$, = P. The number that entered 2 s ago and stay 2 s or more is $P(p_2 + p_3 + ... + p_\tau + ... + p_T)$. This is less than P because Pp_1 molecules, that entered 2 s ago, have now left the system. The number that entered 3 s ago and stay 3 s or more is $P(p_3 + ... + p_\tau + ... + p_T)$, and so on up until the oldest molecules in the system which entered T s ago. Addition gives the total number of molecules in the system as

$$
\begin{aligned}
& P(p_1 + p_2 + p_3 + ... + p_\tau + ... + p_T) \\
+ \quad & P(p_2 + p_3 + ... + p_\tau + ... + p_T) \\
+ \quad & P(p_3 + ... + p_\tau + ... + p_T) \\
+ & \\
... & \\
+ \quad & P(p_\tau + ... + p_T) \\
+ & \\
... & \\
+ \quad & P(p_T) \\
& \\
= & P(p_1 + 2p_2 + 3p_3 + ... + \tau p_\tau + ... + Tp_T)
\end{aligned}
$$

So the total number of carbon molecules in the system (B) is $P\sum_\tau tp_\tau$. $\sum_\tau tp_\tau$ is by definition the average residence time of a carbon molecule in the system, and so average residence time = B/P (Eq. 1, main text).

2. Proof of Equation 7 (main text)

TST_C is the sum of the flows through each compartment that have previously passed through them, and TST is given by Eq. 6 (main text). We assume there is just one compartment at each trophic level and that the flow from decomposers goes only to level 2. We define d_1, d_2 and P_2 as in the main text, and write d_1d_2 = d. Then to derive an equation for FCI we go through the compartments one at a time, calculating how much of their outflow returns to them. The outflow from decomposers is $d(P + P_2\frac{1-t^{n-1}}{1-t})$, of which a proportion d_1 returns directly to decomposers. A further proportion td_1 returns to decomposers from level 3, t^2d_1 from level 4, and so on, giving in all

$$d(P + P_2\frac{1-t^{n-1}}{1-t})d_1\frac{1-t^{n-1}}{1-t} \qquad \text{Eq. S1}$$

This is the flow through decomposers that has passed through them before.

The flow into level 2 is P_2, of which dP_2 returns to level 2 directly, P_2td returns via level 3 and so on, giving a total of $P_2 d\,\frac{1-t^{n-1}}{1-t}$ for the flow through level 2 that has passed through level 2 before.

The flow into level 3 is P_2t, of which dt returns to level 3 without going through any higher level, t^2d returns via level 4 and so on, giving a total of $P_2d(t^2 + t^3 + t^4 + \ldots + t^{n-3})$.

Similarly the flow into level 4 that has been there before is $P_2d(t^4 + t^5 + t^6 + \ldots + t^{n-4})$, and so on, so the total for non-decomposers is

$$\frac{P_2 d}{1-t}\left\{\frac{1-t^{2n-2}}{1-t^2} - \frac{t^{n-1}-t^{2n-2}}{1-t}\right\} \quad \text{Eq. S2}$$

Adding together expressions S1 and S2 gives TST_c as

$$TST_c = \frac{d}{1-t}\left(Pd_1(1-t^{n-1}) + P_2\left\{d_1\frac{\left(1-t^{n-1}\right)^2}{1-t} + \frac{1-t^{2n-2}}{1-t^2} - \frac{t^{n-1}-t^{2n-2}}{1-t}\right\}\right) \quad \text{Eq. S3}$$

FCI can now be obtained as $FCI = 100 \times TST_C / TST$.

3. Proof that FCI ~ 100 $d_1d_2(d_1 + t)$, when t, d_1 and d_2 are small (main text)

To first order in t, d_1 and d_2, Eqs. 6 and 7 (main text) give

$$P_2 = Pt \quad \text{Eq. S4}$$

$$TST = P \quad \text{Eq. S5}$$

$$TST_c = d_1d_2(Pd_1 + Pt) \quad \text{Eq. S6}$$

It follows from Eq. S4 to S6 that FCI = 100 TST_c/TST ~ 100 $d_1d_2(d_1 + t)$

Table S1. Summary parameter values for 37 ecological steady-state trophic networks we constructed (see Fig. 1 & 3). **Model** is model number (see Fig. 1, Fig. S1); **Hab** is habitat (T, terrestrial, M, pelagic marine); **PComp** is total number of primary producer compartments; **Comp** is total number of trophic compartments; **TL** is total number of trophic levels; **L/C** is linear (L, no recycling) or cyclic (C, with recycling); **Temp** is mean environmental temperature, and is assumed to approximately equal ectotherm body temperature (Kelvin); **GPP** is gross primary production (kg C/yr m^2); **PMass** is mean size of an individual primary producer (kg C); $\boldsymbol{\beta}$ is the mass scaling exponent (see Eq. 3, main text); $\mathbf{TTE_{1\text{-}2}}$ is trophic transfer efficiency from the first to second trophic level (all other TTE's = 0.1, except to and from decomposers [see); $\mathbf{TTE}\boldsymbol{d_1}$ is trophic transfer efficiency to the decomposer compartment (if present); $\mathbf{TTE}\boldsymbol{d_2}$ is trophic transfer efficiently from the decomposer apartment (if present); $\boldsymbol{B_{eco}}$ is total biomass of the ecosystem (kg C/m^2); $\hat{\boldsymbol{t}}_{\boldsymbol{eco}}$ is total residence time of carbon within the ecosystems (yr); $\boldsymbol{GPP/B_{eco}}$ (yr); **FCI** is Finn Cycling Index; and **TST** is total systems throughput (kg C/yr m^2). For additional details about each model see Fig. S1, or contact the corresponding author.

Model	Hab	PComp	Comp	TL	L/C	Temp	*GPP*	PMass	β	$TTE_{1\text{-}2}$	TTEd_1	TTEd_2	B_{eco}	$\hat{t}_{eco}$	GPP/B_{eco}	*FCI*	*TST*
1a	T	1	4	4	L	293	0.6	100	0.75	0.10	0.00	0.00	66.24	110.39	0.0091	0	0.667
1b	T	1	4	4	L	293	0.6	10	0.75	0.10	0.00	0.00	37.35	62.25	0.0161	0	0.667
1c	T	1	4	4	L	293	0.6	1	0.75	0.10	0.00	0.00	21.10	35.17	0.0284	0	0.667
1d	T	1	4	4	L	293	0.6	0.1	0.75	0.10	0.00	0.00	11.97	19.94	0.0501	0	0.667
1e	T	1	4	4	L	293	0.6	0.01	0.75	0.10	0.00	0.00	6.83	11.38	0.0879	0	0.667
1f	T	1	4	4	L	293	0.6	0.001	0.75	0.10	0.00	0.00	3.94	6.57	0.1523	0	0.667
1g	T	1	4	4	L	293	0.06	0.001	0.75	0.10	0.00	0.00	0.39	6.57	0.1523	0	0.067
1h	T	1	4	4	L	293	0.6	100	0.66	0.10	0.00	0.00	95.53	159.21	0.0063	0	0.667
1i	T	1	4	4	L	293	0.6	10	0.66	0.10	0.00	0.00	44.74	74.57	0.0134	0	0.667
1j	T	1	4	4	L	293	0.6	1	0.66	0.10	0.00	0.00	20.99	34.98	0.0286	0	0.667
1k	T	1	4	4	L	293	0.6	0.1	0.66	0.10	0.00	0.00	9.88	16.46	0.0607	0	0.667
1l	T	1	4	4	L	293	0.6	0.01	0.66	0.10	0.00	0.00	4.68	7.80	0.1282	0	0.667
1m	T	1	4	4	L	293	0.6	0.001	0.66	0.10	0.00	0.00	2.25	3.75	0.2667	0	0.667
1n	T	1	4	4	L	293	0.06	0.001	0.66	0.10	0.00	0.00	0.23	3.75	0.2667	0	0.067
2a	T	1	5	4	C	293	0.6	100	0.75	0.01	0.40	0.50	66.77	111.28	0.0090	10.77	1.200
2b	T	1	5	4	C	293	0.6	10	0.75	0.01	0.40	0.50	37.88	63.14	0.0158	10.77	1.200
2c	T	1	5	4	C	293	0.6	1	0.75	0.01	0.40	0.50	21.64	36.06	0.0277	10.77	1.200
2d	T	1	5	4	C	293	0.6	0.1	0.75	0.01	0.40	0.50	12.50	20.83	0.0480	10.77	1.200
2e	T	1	5	4	C	293	0.6	0.01	0.75	0.01	0.40	0.50	7.36	12.27	0.0815	10.77	1.200
2f	T	1	5	4	C	293	0.6	0.001	0.75	0.01	0.40	0.50	4.47	7.46	0.1341	10.77	1.200
2g	T	1	5	4	C	293	0.06	0.001	0.75	0.01	0.40	0.50	0.45	7.46	0.1341	10.77	0.120
2h	T	1	5	4	C	293	0.6	100	0.75	0.01	0.40	0.10	66.16	110.27	0.0091	1.61	0.951
3	M	1	5	5	L	293	0.6	1E-12	0.75	0.10	0.00	0.00	0.10	0.17	5.7488	0	0.667
4a	M	1	6	5	C	293	0.6	1E-12	0.75	0.10	0.40	0.50	0.35	0.60	1.6918	10.69	0.000
4b	M	1	6	5	C	293	0.06	1E-12	0.75	0.10	0.40	0.10	0.02	0.25	3.9206	1.67	0.000
5	M	1	3	3	L	293	0.6	1E-12	0.75	0.10	0.00	0.00	0.97	1.61	0.6204	0	0.666
6a	M	1	4	3	C	293	0.6	1E-12	0.75	0.10	0.40	0.50	3.69	6.16	0.1624	10.87	1.200
6b	M	1	4	3	C	280	0.6	1E-12	0.75	0.10	0.40	0.50	9.65	16.09	0.0622	10.87	1.200
6c	M	1	4	3	C	300	0.6	1E-12	0.75	0.10	0.40	0.50	2.53	4.21	0.2375	10.87	1.200
6d	M	1	4	3	C	293	0.6	1E-12	0.75	0.10	0.40	0.10	1.41	2.36	0.4243	1.53	0.972
7a	T	2	7	5	L	293	0.6	92.24	0.75	0.10	0.00	0.00	36.95	61.57	0.0162	0	0.666
7b	T	2	7	5	L	300	0.6	92.24	0.75	0.10	0.00	0.00	20.75	34.58	0.0289	0	0.666
7c	T	2	7	5	L	280	0.6	92.24	0.75	0.10	0.00	0.00	119.59	199.32	0.0050	0	0.666
8	T	2	8	5	C	293	0.6	92.24	0.75	0.10	0.40	0.50	37.62	62.71	0.0159	10.13	1.200
9	T	1	6	5	L	280	0.09	0.001	0.75	0.10	0.00	0.00	2.13	23.71	0.0422	0	0.100
10	T	1	6	5	L	280	0.09	10	0.75	0.10	0.00	0.00	18.69	207.63	0.0048	0	0.100
11a	M	3	9	4	L	293	0.6	1.25E-09	0.75	0.10	0.00	0.00	0.52	0.86	1.1604	0	0.666

Table S2. Empirical data for the body size dependence of carbon and nitrogen half-life within individual organisms (see Fig. 4A). **Taxa** is broad taxonomic group; **Mass** is wet mass of the entire organism (g); **Tissue type** is the tissue used to estimate half-life; **HL** is half-life (measured as the amount of time required for the stable-isotopic signature of the tissue to reach a midpoint value between the enriched and original value, see original sources for exact equations) (d); **HL15°C** is the temperature corrected half-life to 15°C, using Eq. 3 (main text); **Thermy** is 'Endo' for endotherm, and 'Ecto' for ectotherm; **Temp** is body temperature, for ecotherms it is assumed to be equivalent to environmental temperature and for endotherms 37°C; **Source** is data source from which data was obtained; and **Original Source** is the original source from which Source papers obtained data (see Table S3 for full citations).

Element	Taxa	Species	Common name	Mass	Tissue type	HL	HL15°C	Thermy	Temp	Source	Original source
Carbon	Bird	*Aythya valisineria*	Canvasback	1248	Blood	23	147.27873	Endo	37	[1]	[2]
Carbon	Bird	*Calidris alpina pacifica*	Dunlin	44	Blood	11.2	71.71834	Endo	37	[3]	[4]
Carbon	Bird	*Calidris alpina pacifica*	Dunlin	56	Blood	11.23	71.91044	Endo	37	[1]	[4]
Carbon	Bird	*Catharacta skua*	Great skua	970	Blood	15.1	96.69169	Endo	37	[3]	[5]
Carbon	Bird	*Corvus Brachyrhynchos*	American crow	384.8	Blood (plasma)	2.9	18.56992	Endo	37	[3]	[6]
Carbon	Bird	*Corvus Brachyrhynchos*	American crow	428	Blood	29.8	190.82201	Endo	37	[1]	[6]
Carbon	Bird	*Coturni japonica*	Japanese quail	115	Blood	11.2	71.71834	Endo	37	[3]	[7]
Carbon	Bird	*Coturni japonica*	Japanese quail	115	Bone	173.3	1109.71324	Endo	37	[3]	[7]
Carbon	Bird	*Coturni japonica*	Japanese quail	115	Liver	2.5	16.00855	Endo	37	[3]	[7]
Carbon	Bird	*Coturni japonica*	Japanese quail	115	Muscle (flight)	12.4	79.40244	Endo	37	[3]	[7]
Carbon	Bird	*Dendroica coronata*	Yellow-rumped warbler	12	Blood	10.9	69.79731	Endo	37	[8]	[9]
Carbon	Bird	*Dendroica coronata*	Yellow-rumped warbler	12	Blood (plasma)	1	6.40342	Endo	37	[8]	[9]
Carbon	Bird	*Dendroica coronata*	Yellow-rumped warbler	12.5	Blood	4.5	28.81540	Endo	37	[1]	[10]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Blood	19.3	123.58606	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Blood (plasma)	6.7	42.90293	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Bone (collagen)	20.4	130.62983	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Gizard	14.1	90.28826	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Heart	15.2	97.33203	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Intestine	10.3	65.95525	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Liver	9.8	62.75354	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	22	Muscle (flight)	23.5	150.48044	Endo	37	[8]	[11]
Carbon	Bird	*Passer domesticus*	House sparrow	23	Blood	15.6	99.89340	Endo	37	[1]	[1]
Carbon	Bird	*Sylvia borin*	Garden warbler	24.8	Blood	5.4	34.57848	Endo	37	[3]	[12]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Blood	13.4	85.80587	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Brain	12.8	81.96381	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Gizard	7	44.82396	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Heart	12	76.84107	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Intestine	5.6	35.85917	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Kidney	8	51.22738	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Liver	8.3	53.14841	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Muscle (flight)	14.5	92.84963	Endo	37	[8]	[8]
Carbon	Bird	*Taeniopygia guttata*	Zebra finch	16	Muscle (leg)	18.1	115.90196	Endo	37	[8]	[8]
Carbon	Fish	*Danio rerio*	Zebra danio	0.28	Muscle	53.3	171.99465	Ecto	28.5	[13]	[14]
Carbon	Fish	*Dicentrarchus labrax*	European sea bass	8	Muscle	157.5	119.58432	Ecto	12	[13]	[15]
Carbon	Fish	*Lateolabrax japonicus*	Japanese temperate bass	9.87	Muscle	21	42.59146	Ecto	23	[13]	[16]

Element	Taxa	Species	Common name	Mass	Tissue type	HL	HL15°C	Thermy	Temp	Source	Original source
Carbon	Fish	*Lepomis macrochirus*	Bluegill	0.06	Muscle	18	32.06743	Ecto	21.5	[13]	[13]
Carbon	Fish	*Lepomis macrochirus*	Bluegill	5.38	Muscle	29	51.66419	Ecto	21.5	[13]	[13]
Carbon	Fish	*Lepomis macrochirus*	Bluegill	72.7	Muscle	116	206.65678	Ecto	21.5	[13]	[13]
Carbon	Fish	*Micropterus salmoides*	Largemouth bass	0.52	Muscle	18	32.06743	Ecto	21.5	[13]	[13]
Carbon	Fish	*Micropterus salmoides*	Largemouth bass	5.6	Muscle	25	44.53809	Ecto	21.5	[13]	[13]
Carbon	Fish	*Micropterus salmoides*	Largemouth bass	413	Muscle	173	308.20364	Ecto	21.5	[13]	[13]
Carbon	Fish	*Oreochromis niloticus*	Nile tilapia	23.87	Muscle	23.3	56.06088	Ecto	25	[13]	[17]
Carbon	Fish	*Oreochromis niloticus*	Nile tilapia	24.46	Muscle	26	62.55720	Ecto	25	[13]	[17]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.00067*	Whole organism	8.7	7.24536	Ecto	13	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.00067*	Whole organism	2.9	5.39540	Ecto	22	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.00718*	Whole organism	11.6	9.66048	Ecto	13	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.00718*	Whole organism	5	9.30241	Ecto	22	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.02080*	Whole organism	17.3	14.40745	Ecto	13	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	0.02080*	Whole organism	5.8	10.79080	Ecto	22	[13]	[18]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	58.8	Muscle	69	106.89063	Ecto	19.9	[13]	[19]
Carbon	Fish	*Paralichthys dentatus*	Summer flounder	102	Muscle	49	79.30979	Ecto	20.4	[13]	[19]
Carbon	Fish	*Paralichthys olivaceus*	Japanese flounder	0.26	Muscle	17.3	22.96049	Ecto	18.15	[13]	[20]
Carbon	Fish	*Paralichthys olivaceus*	Japanese flounder	0.26	Muscle	13.9	16.64862	Ecto	17	[13]	[20]
Carbon	Fish	*Paralichthys olivaceus*	Japanese flounder	1.06	Muscle	5	6.84543	Ecto	18.5	[13]	[20]
Carbon	Fish	*Perca flavescens*	Yellow perch	0.11	Muscle	8	14.25219	Ecto	21.5	[13]	[13]
Carbon	Fish	*Perca flavescens*	Yellow perch	2.24	Muscle	58	103.32839	Ecto	21.5	[13]	[13]
Carbon	Fish	*Perca flavescens*	Yellow perch	11.16	Muscle	116	206.65678	Ecto	21.5	[13]	[13]
Carbon	Fish	*Pleuronectes americanus*	Winter flounder	0.00255*	Whole organism	2.2	2.88113	Ecto	18	[13]	[21]
Carbon	Fish	*Pleuronectes americanus*	Winter flounder	0.00322*	Whole organism	4.1	3.41448	Ecto	13	[13]	[21]
Carbon	Fish	*Pomatoschistus minutus*	Sand goby	5.85	Muscle	23.9	28.62604	Ecto	17	[13]	[22]
Carbon	Fish	*Pseudoplatystoma corruscans*	Pintado	0.77	Whole organism	105	291.35423	Ecto	26.69	[13]	[23]
Carbon	Fish	*Sciaenops ocellatus*	Red drum	0.00016*	Whole organism	6	18.57412	Ecto	28	[13]	[24,25]
Carbon	Fish	*Sciaenops ocellatus*	Red drum	0.00496*	Whole organism	5	15.47844	Ecto	28	[13]	[24,25]
Carbon	Fish	*Sciaenops ocellatus*	Red drum	0.00597*	Whole organism	7	15.46772	Ecto	24	[13]	[24,25]
Carbon	Fish	*Solea senegalensis*	Senegalese sole	0.00176*	Whole organism	2.5	4.45380	Ecto	21.5	[13]	[26]
Carbon	Fish	*Solea senegalensis*	Senegalese sole	0.00176*	Whole organism	2.7	4.81011	Ecto	21.5	[13]	[26]
Carbon	Fish	*Solea senegalensis*	Senegalese sole	0.00176*	Whole organism	3.5	6.23533	Ecto	21.5	[13]	[26]
Carbon	Mammal	*Equus caballus*	Horse	409778	Hair	136	870.86556	Endo	37	[3]	[27]
Carbon	Mammal	*Meriones unguiculates*	Gerbil	64.8	Brain	27.7	177.37482	Endo	37	[3]	[28]
Carbon	Mammal	*Meriones unguiculates*	Gerbil	64.8	Fat	15.8	101.17408	Endo	37	[3]	[28]
Carbon	Mammal	*Meriones unguiculates*	Gerbil	64.8	Hair	46.2	295.83815	Endo	37	[3]	[28]
Carbon	Mammal	*Meriones unguiculates*	Gerbil	64.8	Liver	6.4	40.98190	Endo	37	[3]	[28]
Carbon	Mammal	*Meriones unguiculates*	Gerbil	64.8	Muscle	27.7	177.37482	Endo	37	[3]	[28]
Carbon	Mammal	*Mus musculus*	Mouse	18.55	Blood	16.9	108.21785	Endo	37	[3]	[29]
Carbon	Mammal	*Mus musculus*	Mouse	18.55	Muscle	23.9	153.04181	Endo	37	[3]	[29]
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Blood	20.4	130.62983	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (172 d)	19	Blood	19.8	126.78778	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Brain	17.8	113.98093	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Heart	13.9	89.00758	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Kidney	4.6	29.45574	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Liver	5	32.01711	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (172 d)	19	Liver	7.7	49.30635	Endo	37	[8]	[30]

Element	Taxa	Species	Common name	Mass	Tissue type	HL	HL15°C	Thermy	Temp	Source	Original source
Carbon	Mammal	*Mus musculus*	Mouse (28 d)	19	Muscle (leg)	23.1	147.91907	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse (172 d)	19	Muscle (leg)	18.2	116.54230	Endo	37	[8]	[30]
Carbon	Mammal	*Mus musculus*	Mouse	27.7	Blood	18.6	119.10367	Endo	37	[3]	[3]
Carbon	Mammal	*Rattus norvegicus*	Rat	288	Blood	24.7	158.16455	Endo	37	[3]	[3]
Carbon	Mammal	*Vicugna pacos*	Alpaca	60000	Liver	37.3	238.84768	Endo	37	[8]	[31]
Carbon	Mammal	*Vicugna pacos*	Alpaca	60000	Muscle (leg)	178.7	1144.29173	Endo	37	[8]	[31]
Carbon	Shark	*Carcharhinus plumbeus*	Sandbar shark	5500	Blood	93.25	197.42225	Ecto	23.5	[32]	[32]
Carbon	Shark	*Carcharhinus plumbeus*	Sandbar shark	5500	Muscle	155.2	328.57837	Ecto	23.5	[32]	[32]
Nitrogen	Amphibian	*Rana palmipes*	Tadpole	2.115	Muscle	138.6	293.43403	Ecto	23.5	[33]	[33]
Nitrogen	Bird	*Aythya valisineria*	Canvasback	1250	Blood	23.2	148.55941	Endo	37	[3]	[2]
Nitrogen	Bird	*Calidris alpina pacifica*	Dunlin	44	Blood	10	64.03423	Endo	37	[3]	[4]
Nitrogen	Bird	*Catharacta skua*	Great skua	970	Blood	12	76.84107	Endo	37	[3]	[5]
Nitrogen	Bird	*Dendroica coronata*	Yellow-rumped warbler	11.5	Blood	7.5	48.02567	Endo	37	[3]	[10]
Nitrogen	Bird	*Sylvia borin*	Garden warbler	24.8	Blood	8.1	51.86772	Endo	37	[3]	[12]
Nitrogen	Crustacean	*Euphausiacea* spp.	Krill	0.01	Whole organism	784	159.87826	Ecto	-1.5	[33]	[34]
Nitrogen	Crustacean	*Euphausiacea* spp.	Krill	0.01	Whole organism	156	43.08434	Ecto	1.5	[33]	[34]
Nitrogen	Fish	*Ancistrus triradiatus*	Armored catfish	1.44	Blood	16.9	35.77947	Ecto	23.5	[33]	[33]
Nitrogen	Fish	*Ancistrus triradiatus*	Armored catfish	1.44	Muscle	18.2	38.53174	Ecto	23.5	[33]	[33]
Nitrogen	Fish	*Ancistrus triradiatus*	Armored catfish	1.44	Muscle (fin)	12.2	25.82897	Ecto	23.5	[33]	[33]
Nitrogen	Fish	*Paralichthys dentatus*	Summer flounder	0.01	Whole organism	8	6.66240	Ecto	13	[33]	[18]
Nitrogen	Fish	*Paralichthys dentatus*	Summer flounder	0.01	Whole organism	3	5.58145	Ecto	22	[33]	[18]
Nitrogen	Fish	*Paralichthys dentatus*	Summer flounder	0.1	Whole organism	14	11.65921	Ecto	13	[33]	[18]
Nitrogen	Fish	*Paralichthys dentatus*	Summer flounder	0.1	Whole organism	6	11.16290	Ecto	22	[33]	[18]
Nitrogen	Fish	*Pleuronectes americanus*	Winter flounder	0.00255*	Whole organism	3.1	4.05978	Ecto	18	[21]	[21]
Nitrogen	Fish	*Pleuronectes americanus*	Winter flounder	0.00322*	Whole organism	3.9	3.24792	Ecto	13	[21]	[21]
Nitrogen	Fish	*Salvelinus namaycush*	Lake trout	55	Whole organism	69	45.97915	Ecto	10.6	[33]	[35]
Nitrogen	Gastropod	*Elimia sp.*	Snail	0.1	Whole organism	69	54.36701	Ecto	12.4	[33]	[36]
Nitrogen	Gastropod	*Lavigeria grandis*	Snail	0.495	Muscle	49.5	129.60970	Ecto	26	[33]	[33]
Nitrogen	Gastropod	*Tarebia granifera*	Snail	0.055	Muscle	20.2	42.76599	Ecto	23.5	[33]	[33]
Nitrogen	Mammal	*Mus musculus*	Mouse	18.55	Blood	19.3	123.58606	Endo	37	[3]	[29]
Nitrogen	Mammal	*Mus musculus*	Mouse	18.55	Liver	7.3	46.74498	Endo	37	[3]	[29]
Nitrogen	Mammal	*Mus musculus*	Mouse	18.55	Muscle	24.8	158.80489	Endo	37	[3]	[29]
Nitrogen	Mammal	*Mus musculus*	Mouse	27.7	Blood	19.6	125.50709	Endo	37	[3]	[3]
Nitrogen	Mammal	*Rattus norvegicus*	Rat	288	Blood	21.3	136.39291	Endo	37	[3]	[3]
Nitrogen	Shark	*Carcharhinus plumbeus*	Sandbar shark	5500	Blood	60.6	128.29799	Ecto	23.5	[32]	[32]
Nitrogen	Shark	*Carcharhinus plumbeus*	Sandbar shark	5500	Muscle	92.35	195.51683	Ecto	23.5	[32]	[32]

* Dry mass converted to wet mass using data for Chinook salmon (*Oncorhynchus tshawytscha*) – dry mass is 14.9% of wet mass [37].

Table S3. Data sources for carbon and nitrogen half-life within individual organisms (see Table S2).

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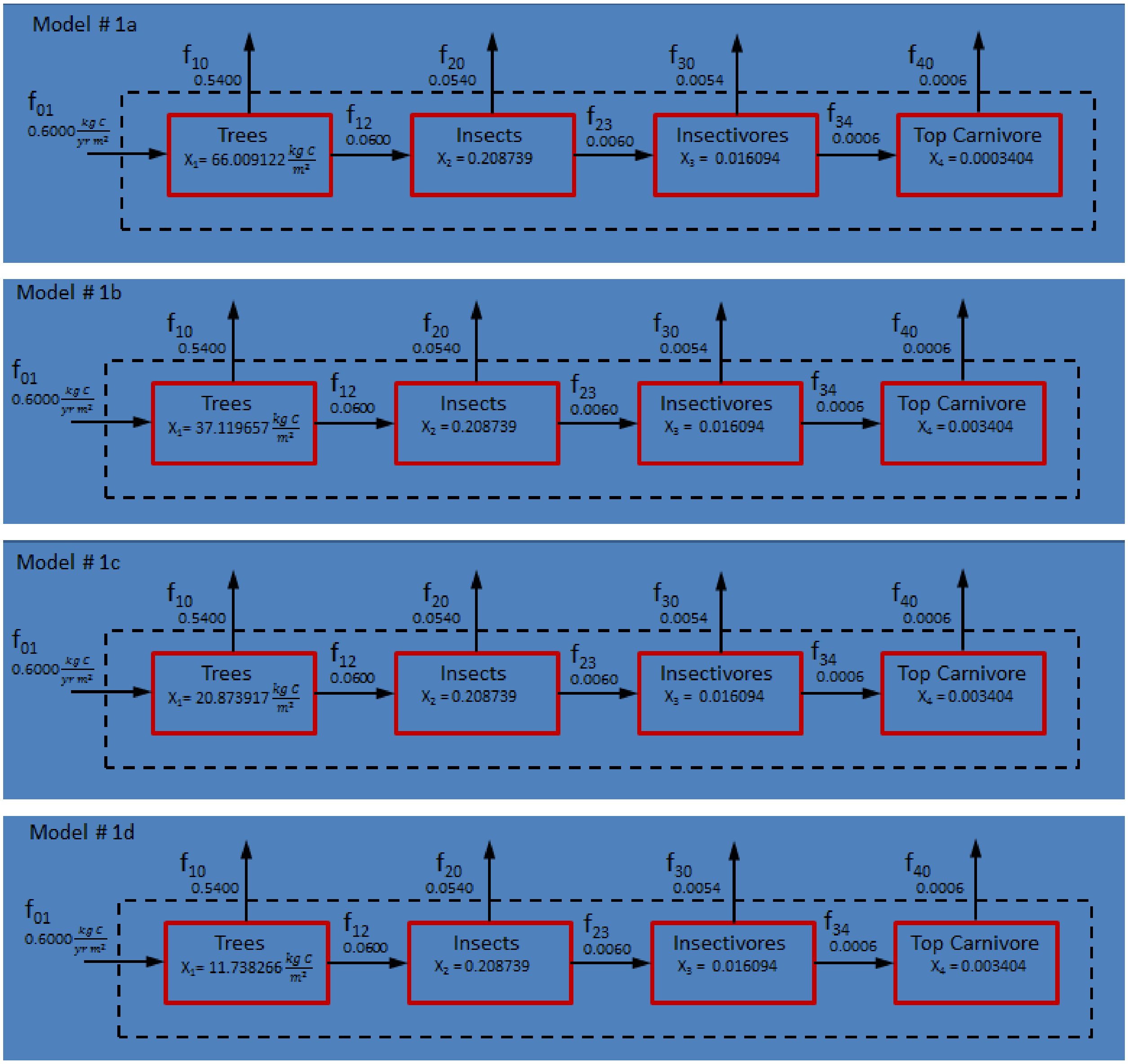
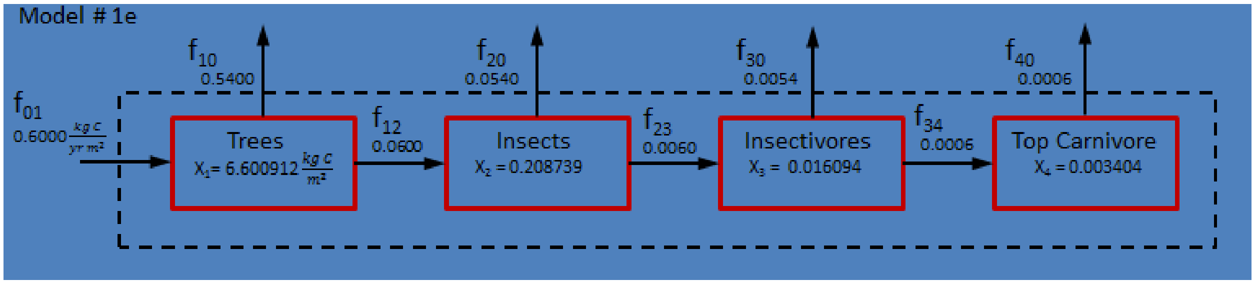
Figure S1. The 37 ecological steady-state (inputs equal outputs) carbon flow models we constructed for numerical evaluation. In each trophic compartment (red box) is shown the ecological functional group (e.g., trees, insects, top carnivore) and total compartment biomass X_i (kg C/m^2). Black arrows in and out of compartments represent carbon flows in and out, respectively. The incoming flow on the left of the system (f_{01}) is GPP (kg C/yr m^2) and all outgoing flows f_{i0} represent respiration (kg C/yr m^2). Dotted line represents the system boundary. See Table S1 for summary data for each model, and Materials and Methods for details of model calculations.

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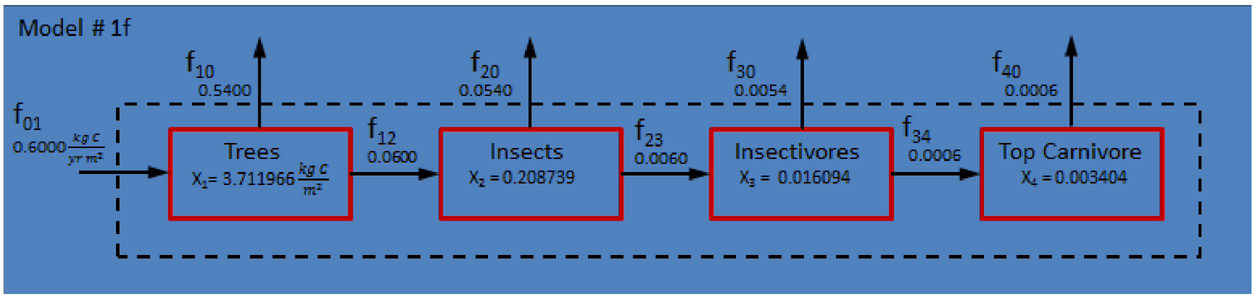
f30 0.0054
f40 0.0006
f01 0.6000 kg C / yr m²
Trees X1= 6.600912 kg C / m²
f12 0.0600
Insects X2 = 0.208739
f23 0.0060
Insectivores X3 = 0.016094
f34 0.0006
Top Carnivore X4 = 0.003404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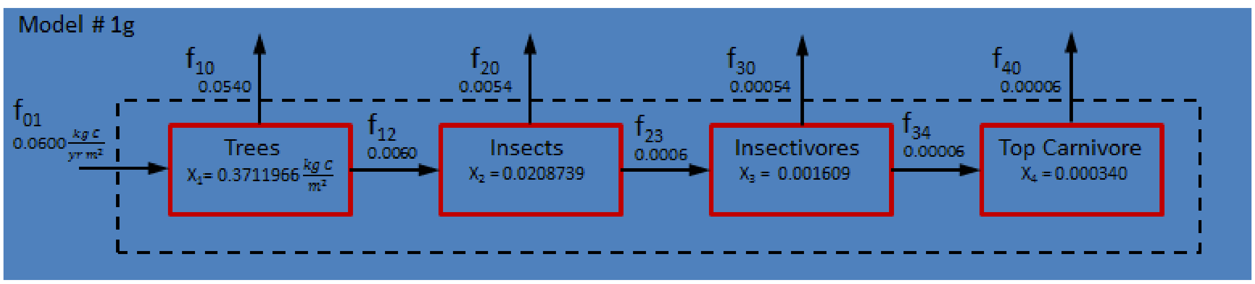
Trees X1= 3.711966 kg C / m²
f12 0.0600
Insects X2 = 0.208739
f23 0.0060
Insectivores X3 = 0.016094
f34 0.0006
Top Carnivore X4 = 0.003404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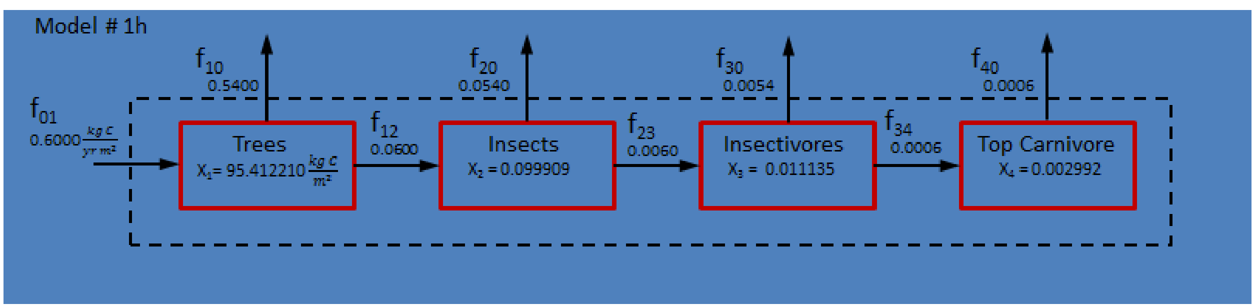
Insects X2 = 0.0208739
f23 0.0006
Insectivores X3 = 0.001609
f34 0.00006
Top Carnivore X4 = 0.000340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f12 0.0600
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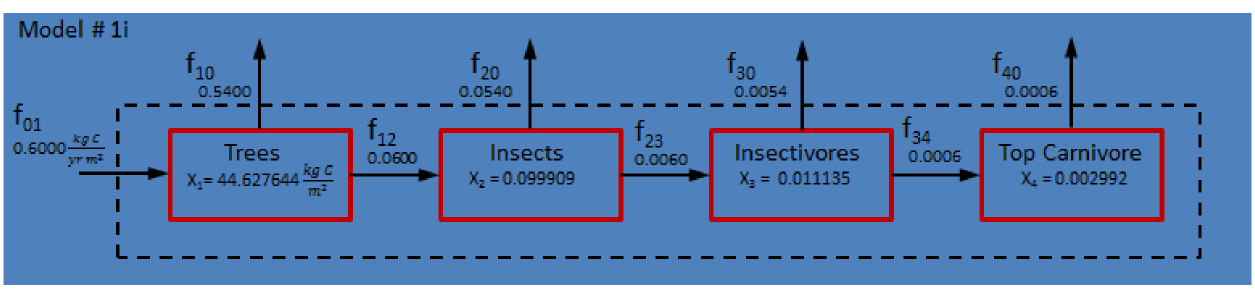
f23 0.0060
Insectivores X3 = 0.011135
f34 0.0006
Top Carnivore X4 = 0.002992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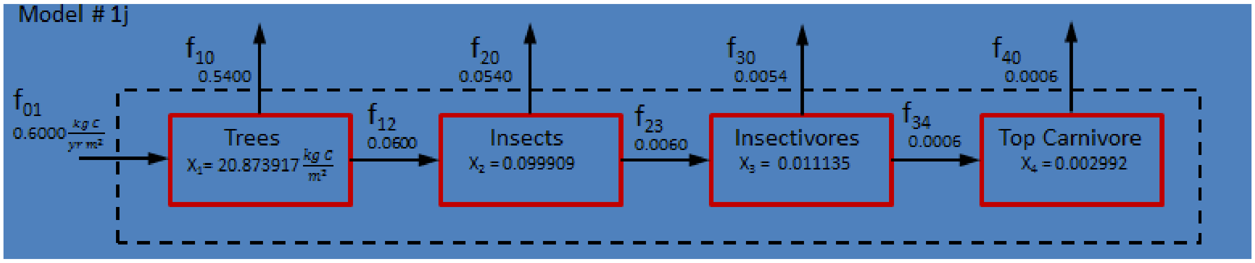
Insects X2 = 0.099909
f23 0.0060
Insectivores X3 = 0.011135
f34 0.0006
Top Carnivore X4 = 0.002992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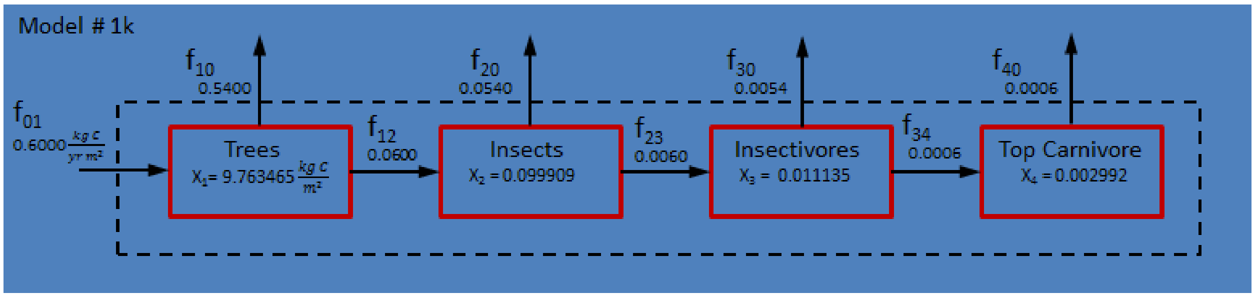
Insectivores X3 = 0.011135
f34 0.0006
Top Carnivore X4 = 0.002992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Trees X1= 9.763465 kg C / m²
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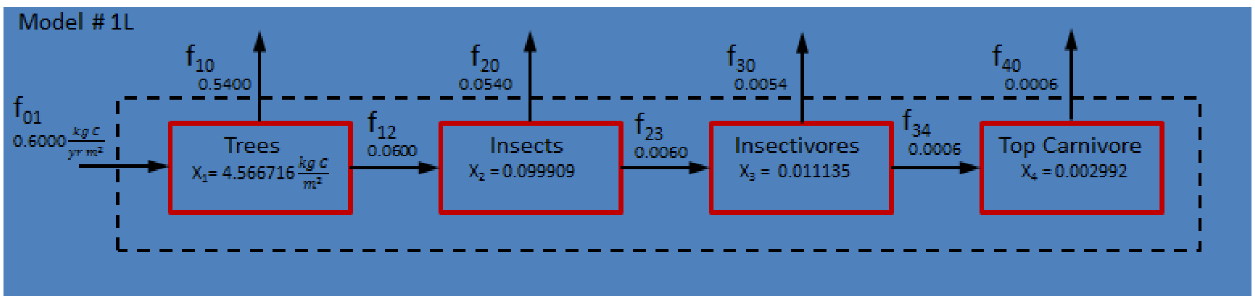
Insectivores X3 = 0.011135
f34 0.0006
Top Carnivore X4 = 0.002992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Insects X2 = 0.099909
f23 0.0060
Insectivores X3 = 0.011135
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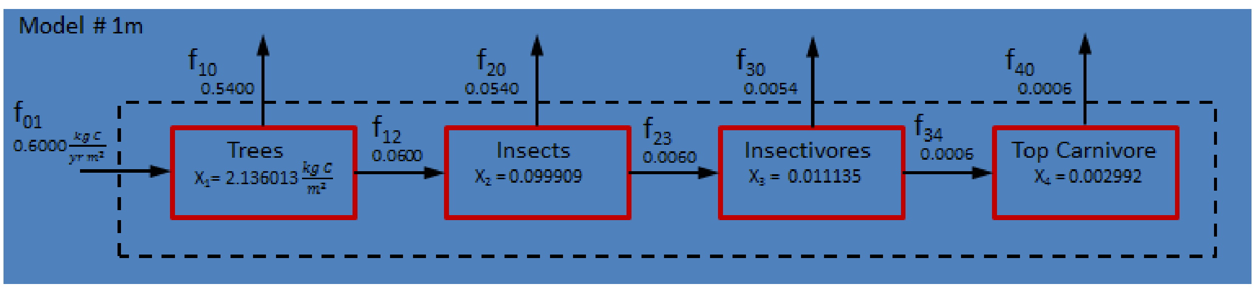
Top Carnivore X4 = 0.002992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f40 0.0006
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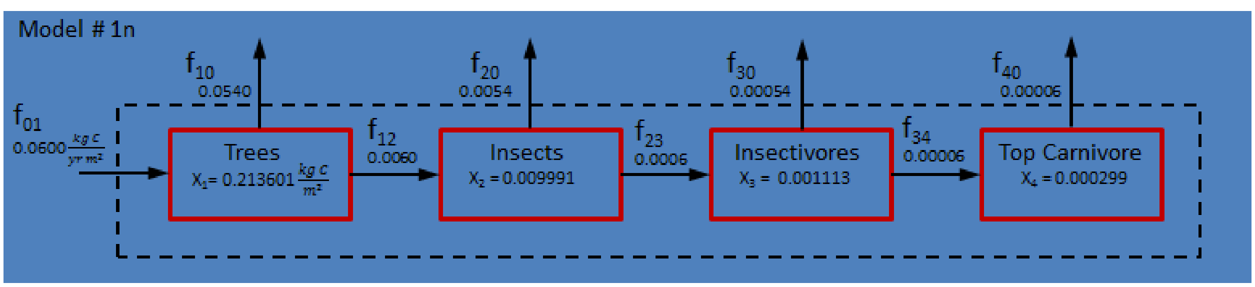
Trees X1= 2.136013 kg C / m²
f12 0.0600
Insects X2 = 0.099909
f23 0.0060
Insectivores X3 = 0.011135
f34 0.0006
Top Carnivore X4 = 0.002992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f40 0.00006
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Trees X1= 0.213601 kg C / m²
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Insects X2 = 0.009991
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Insectivores X3 = 0.001113
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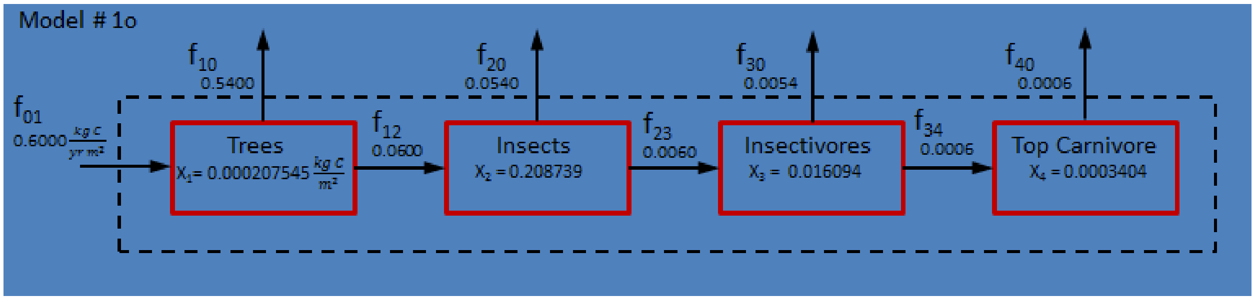
Top Carnivore X4 = 0.000299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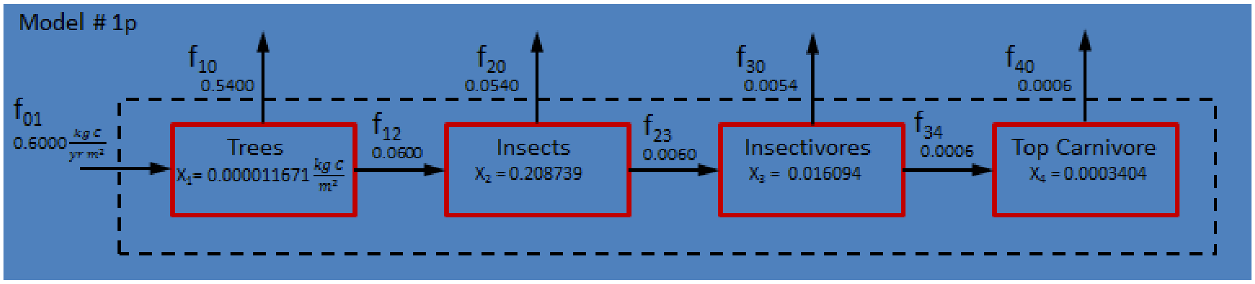
Insects X2 = 0.208739
f23 0.0060
Insectivores X3 = 0.016094
f34 0.0006
Top Carnivore X4 = 0.0003404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Trees X1= 0.000011671 kg c/m²
f12 0.0600
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Insectivores X3 = 0.016094
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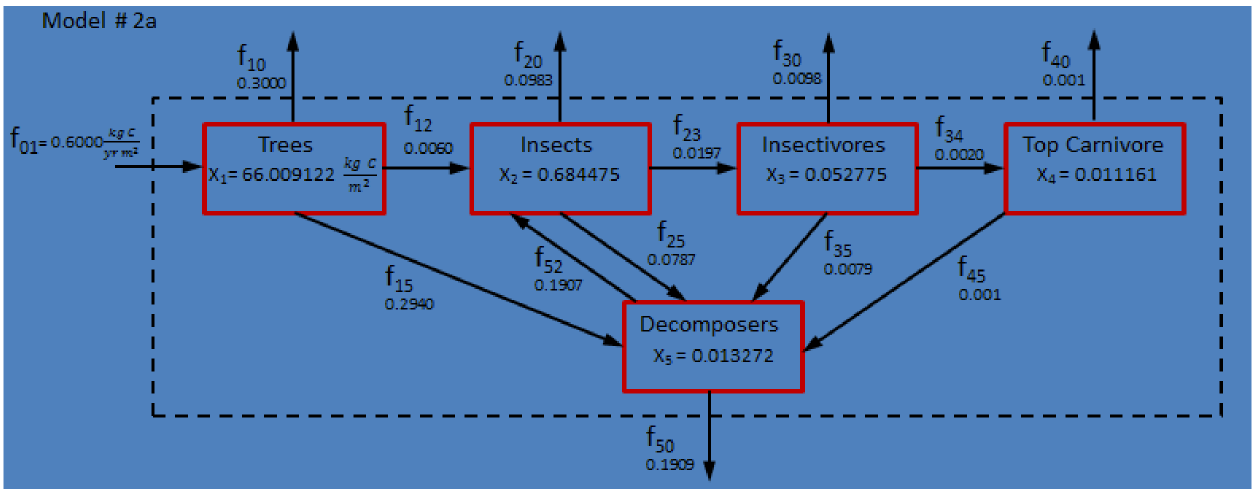
Top Carnivore X4 = 0.0003404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Trees X1= 66.009122 kg c/m²
f12 0.0060
Insects X2 = 0.684475
f23 0.0197
Insectivores X3 = 0.052775
f34 0.0020
Top Carnivore X4 = 0.011161
f15 0.2940
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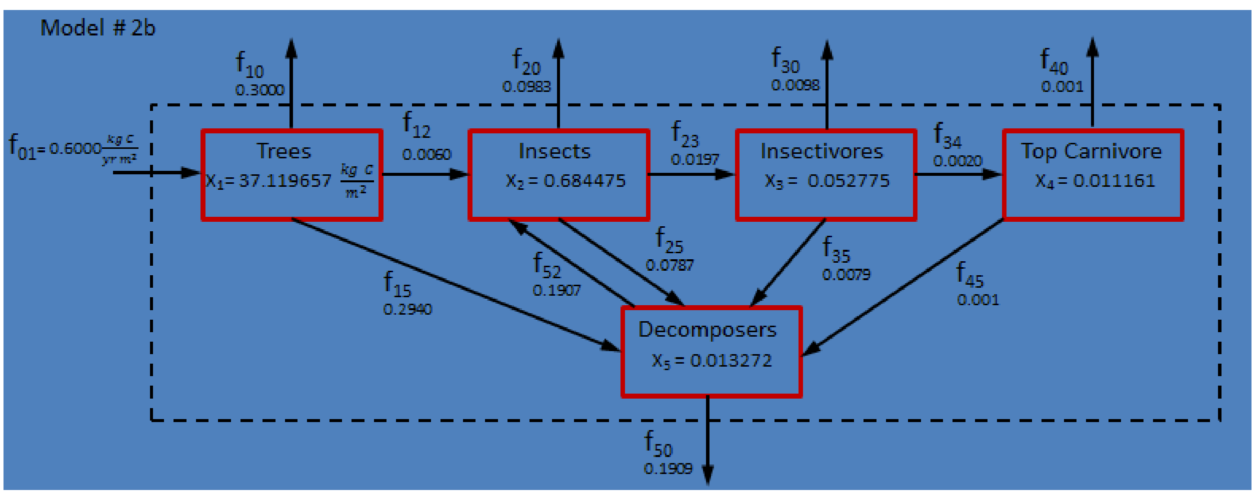
f25 0.0787
f35 0.0079
f45 0.001
Decomposers X5 = 0.013272
f50 0.1909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f30 0.0098
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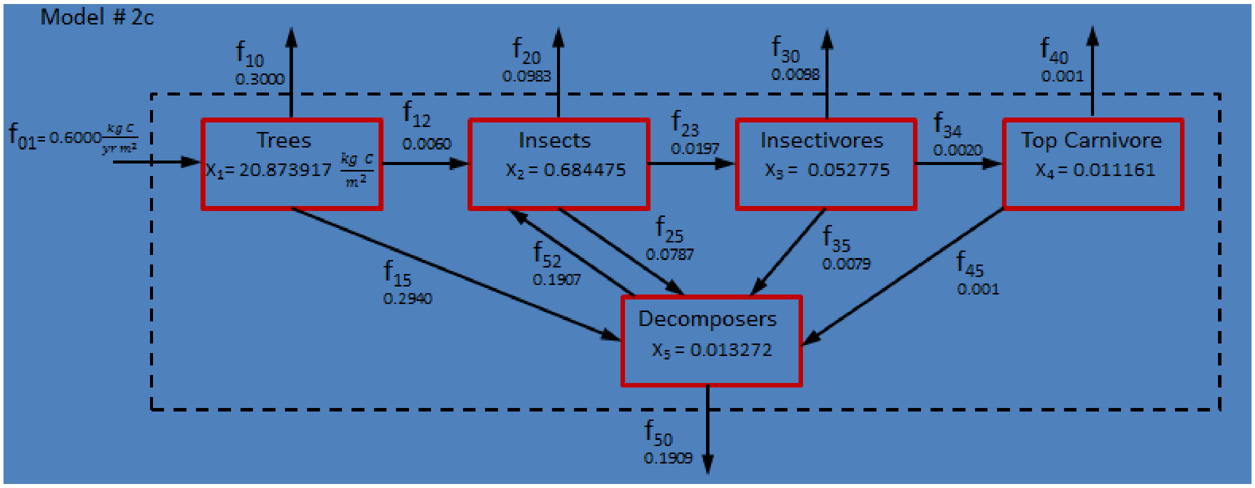
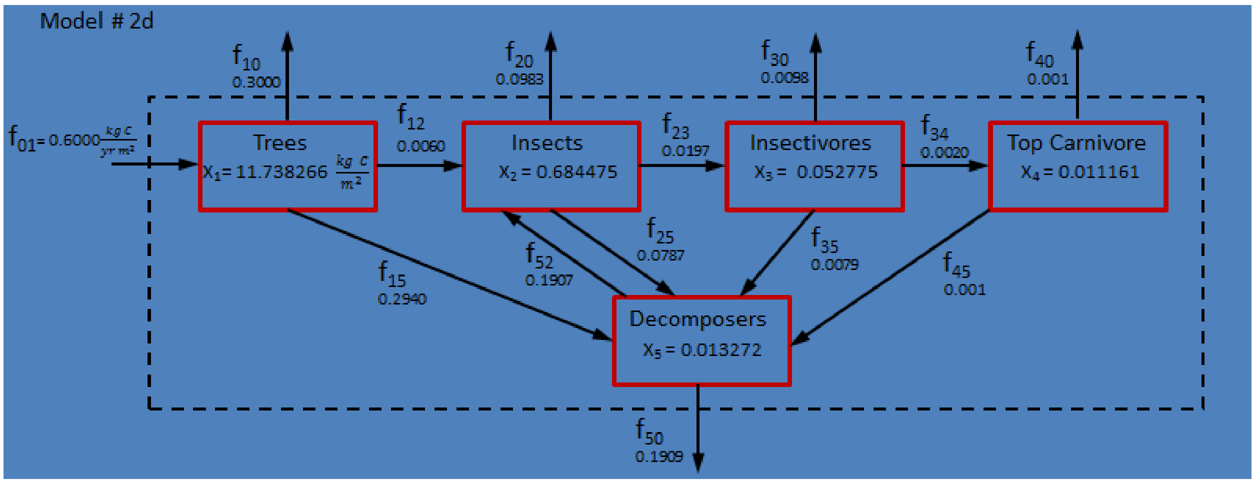
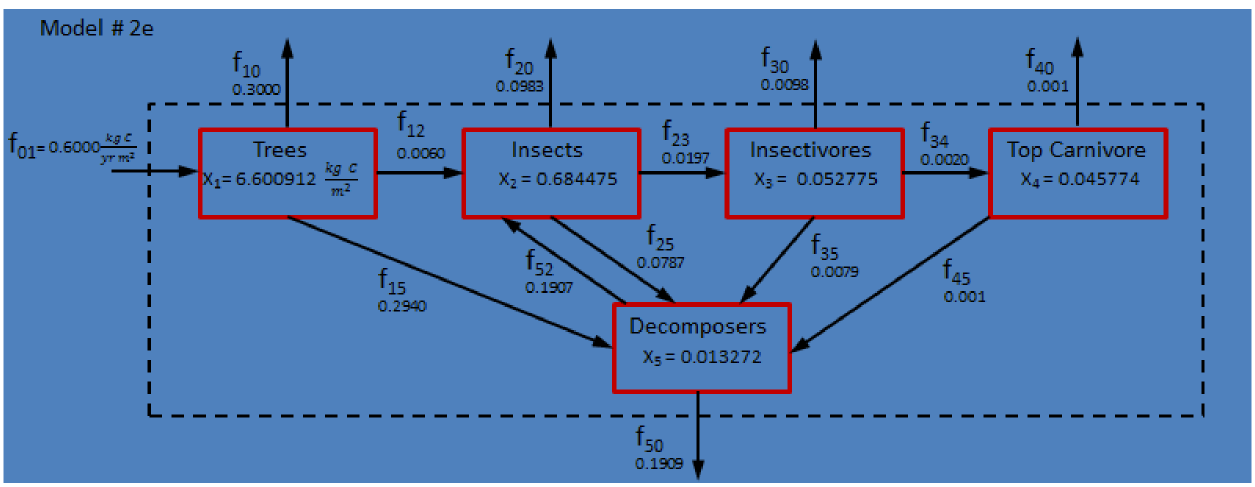
Trees X1= 37.119657 kg c/m²
f12 0.0060
Insects X2 = 0.684475
f23 0.0197
Insectivores X3 = 0.052775
f34 0.0020
Top Carnivore X4 = 0.011161
f15 0.2940
f52 0.1907
f25 0.0787
f35 0.0079
f45 0.001
Decomposers X5 = 0.013272
f50 0.1909



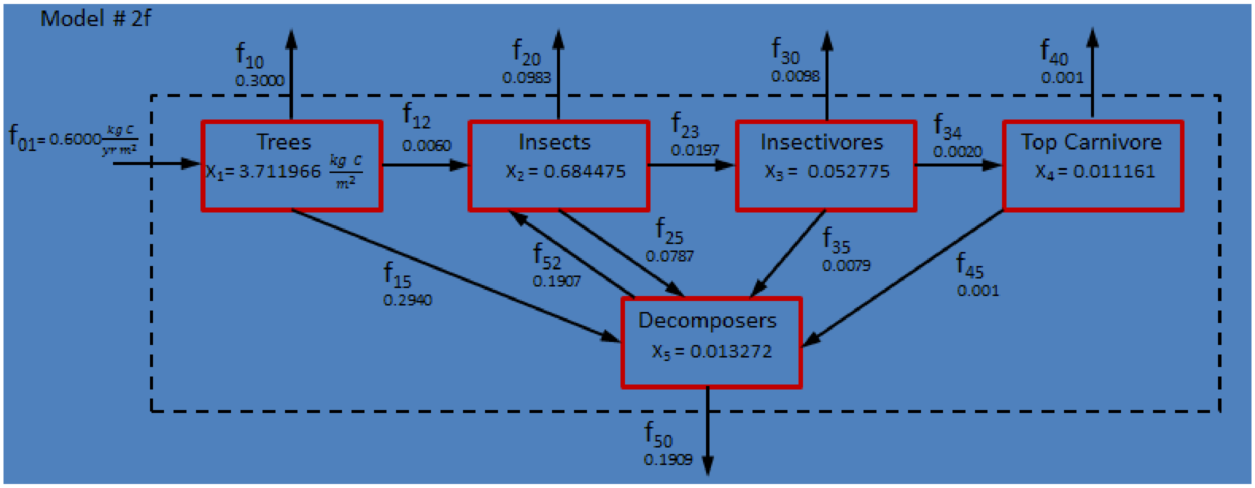
Model # 2c
f10 0.3000
f20 0.0983
f30 0.0098
f40 0.001
f01 = 0.6000 kg c / yr m²
f12 0.0060
f23 0.0197
f34 0.0020
Trees X1 = 20.873917 kg c / m²
Insects X2 = 0.684475
Insectivores X3 = 0.052775
Top Carnivore X4 = 0.011161
f25 0.0787
f35 0.0079
f45 0.001
f52 0.1907
f15 0.2940
Decomposers X5 = 0.013272
f50 0.1909

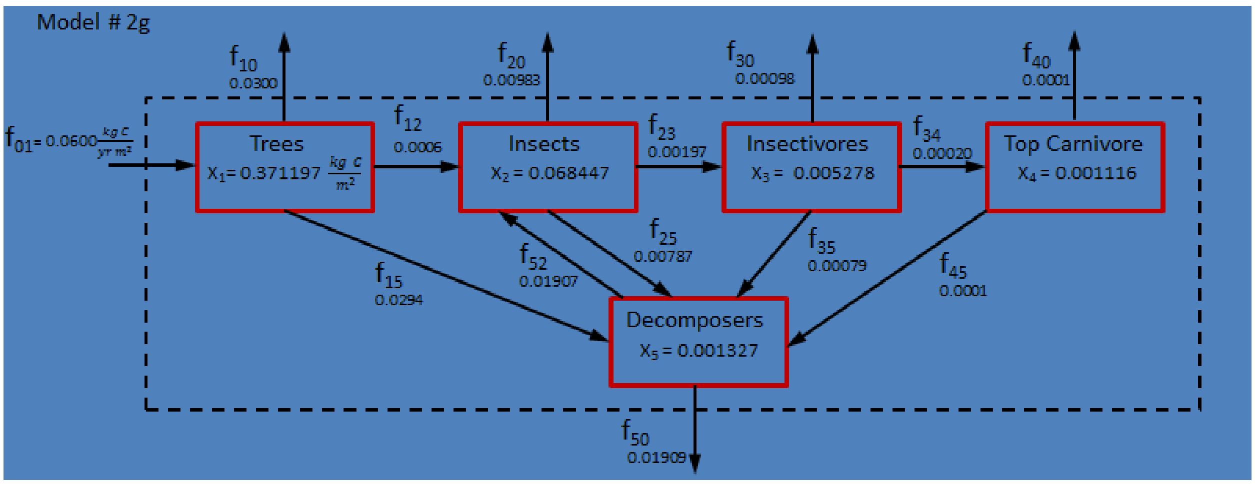


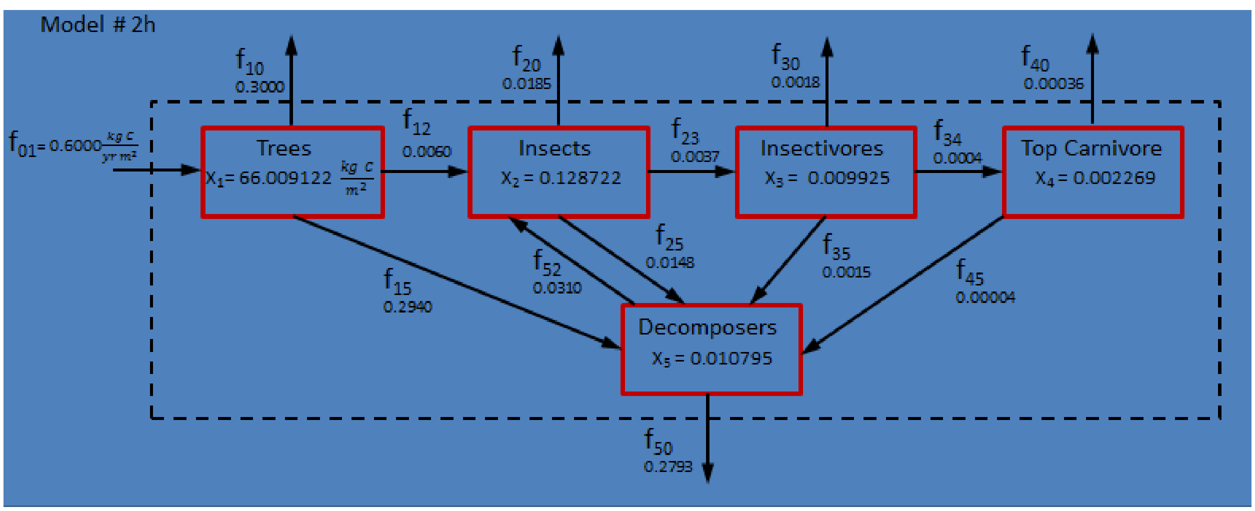
Model # 2d
f10 0.3000
f20 0.0983
f30 0.0098
f40 0.001
f01 = 0.6000 kg c / yr m²
f12 0.0060
f23 0.0197
f34 0.0020
Trees X1 = 11.738266 kg c / m²
Insects X2 = 0.684475
Insectivores X3 = 0.052775
Top Carnivore X4 = 0.011161
f25 0.0787
f35 0.0079
f45 0.001
f52 0.1907
f15 0.2940
Decomposers X5 = 0.013272
f50 0.1909

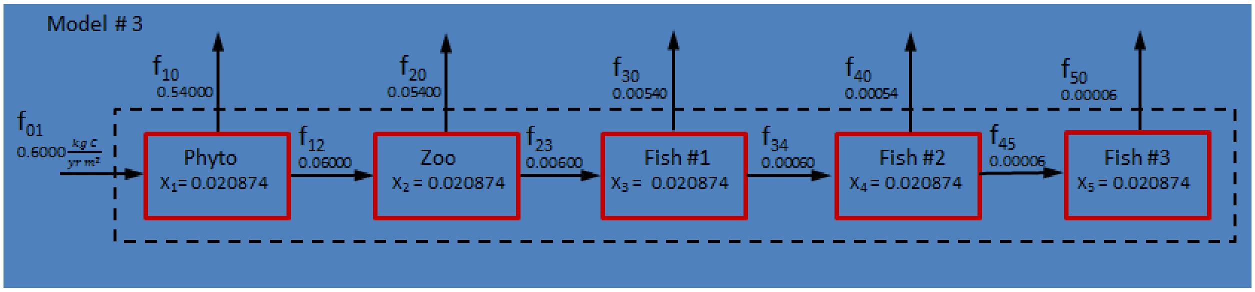


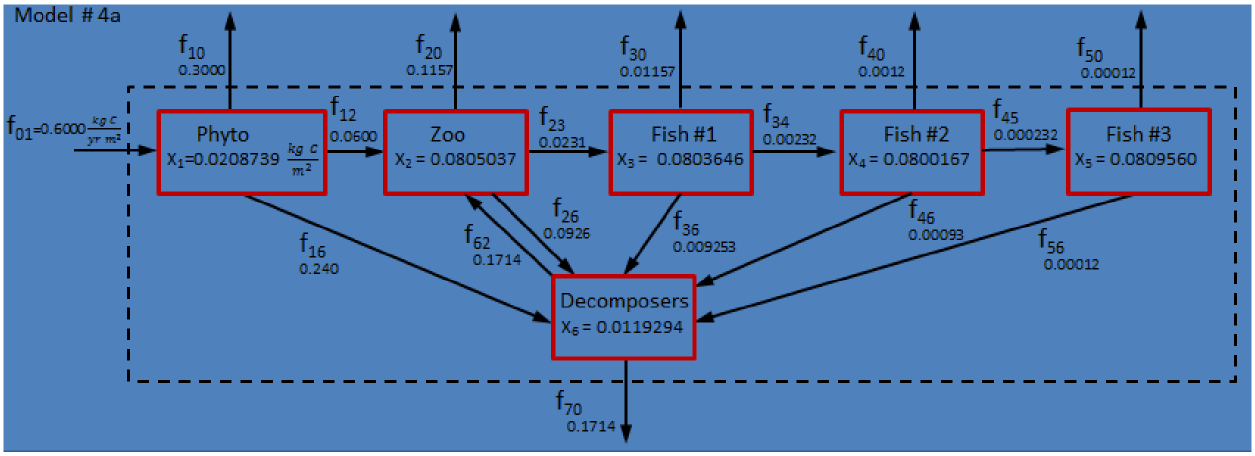
Model # 2e
f10 0.3000
f20 0.0983
f30 0.0098
f40 0.001
f01 = 0.6000 kg c / yr m²
f12 0.0060
f23 0.0197
f34 0.0020
Trees X1 = 6.600912 kg c / m²
Insects X2 = 0.684475
Insectivores X3 = 0.052775
Top Carnivore X4 = 0.045774
f25 0.0787
f35 0.0079
f45 0.001
f52 0.1907
f15 0.2940
Decomposers X5 = 0.013272
f50 0.1909

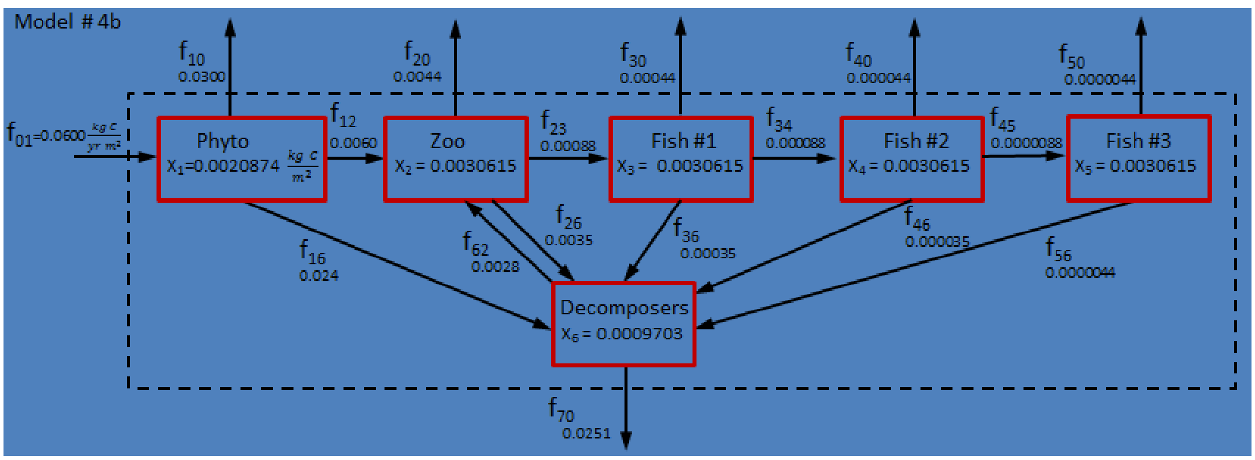

Model # 2f
f01= 0.6000 kg C / yr m²
f10 0.3000
f20 0.0983
f30 0.0098
f40 0.001
f12 0.0060
f23 0.0197
f34 0.0020
Trees
X1= 3.711966 kg C / m²
Insects
X2 = 0.684475
Insectivores
X3 = 0.052775
Top Carnivore
X4 = 0.011161
f25 0.0787
f52 0.1907
f15 0.2940
f35 0.0079
f45 0.001
Decomposers
X5 = 0.013272
f50 0.1909

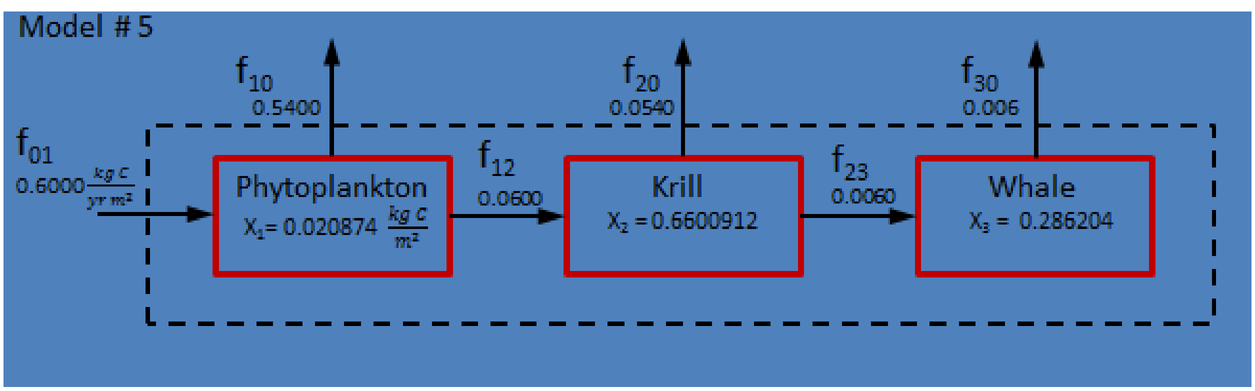

Model # 2g
f01= 0.0600 kg C / yr m²
f10 0.0300
f20 0.00983
f30 0.00098
f40 0.0001
f12 0.0006
f23 0.00197
f34 0.00020
Trees
X1= 0.371197 kg C / m²
Insects
X2 = 0.068447
Insectivores
X3 = 0.005278
Top Carnivore
X4 = 0.001116
f25 0.00787
f52 0.01907
f15 0.0294
f35 0.00079
f45 0.0001
Decomposers
X5 = 0.001327
f50 0.01909

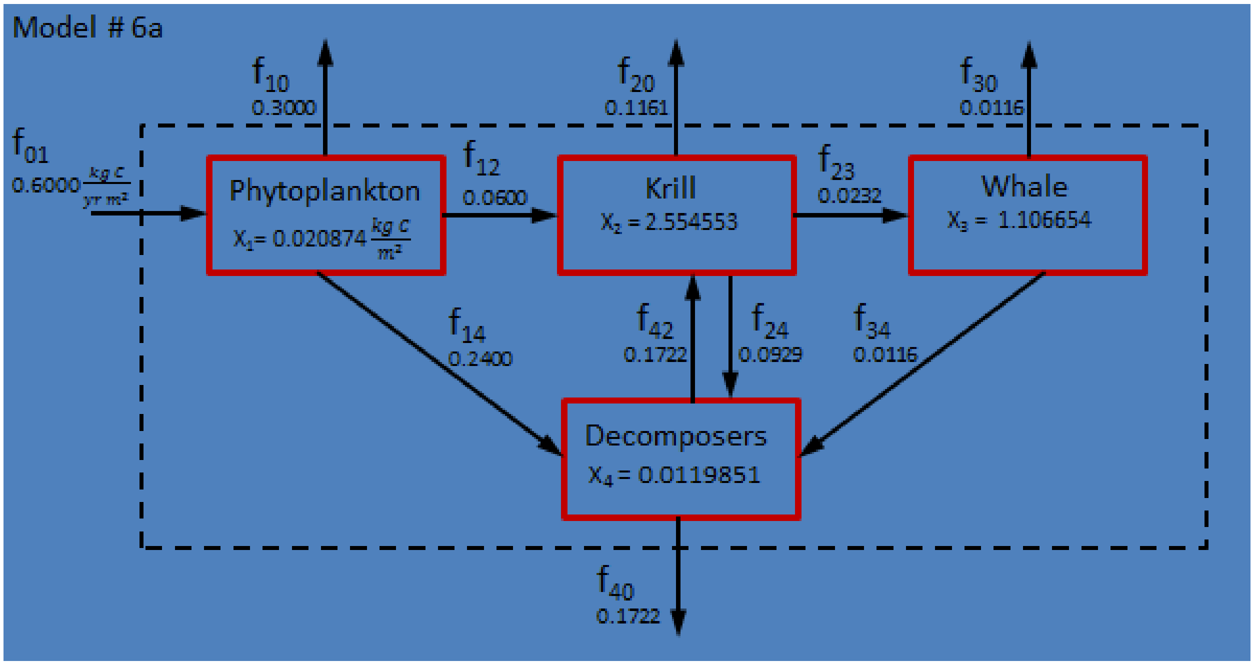

Model # 2h
f01= 0.6000 kg C / yr m²
f10 0.3000
f20 0.0185
f30 0.0018
f40 0.00036
f12 0.0060
f23 0.0037
f34 0.0004
Trees
X1= 66.009122 kg C / m²
Insects
X2 = 0.128722
Insectivores
X3 = 0.009925
Top Carnivore
X4 = 0.002269
f25 0.0148
f52 0.0310
f15 0.2940
f35 0.0015
f45 0.00004
Decomposers
X5 = 0.010795
f50 0.2793

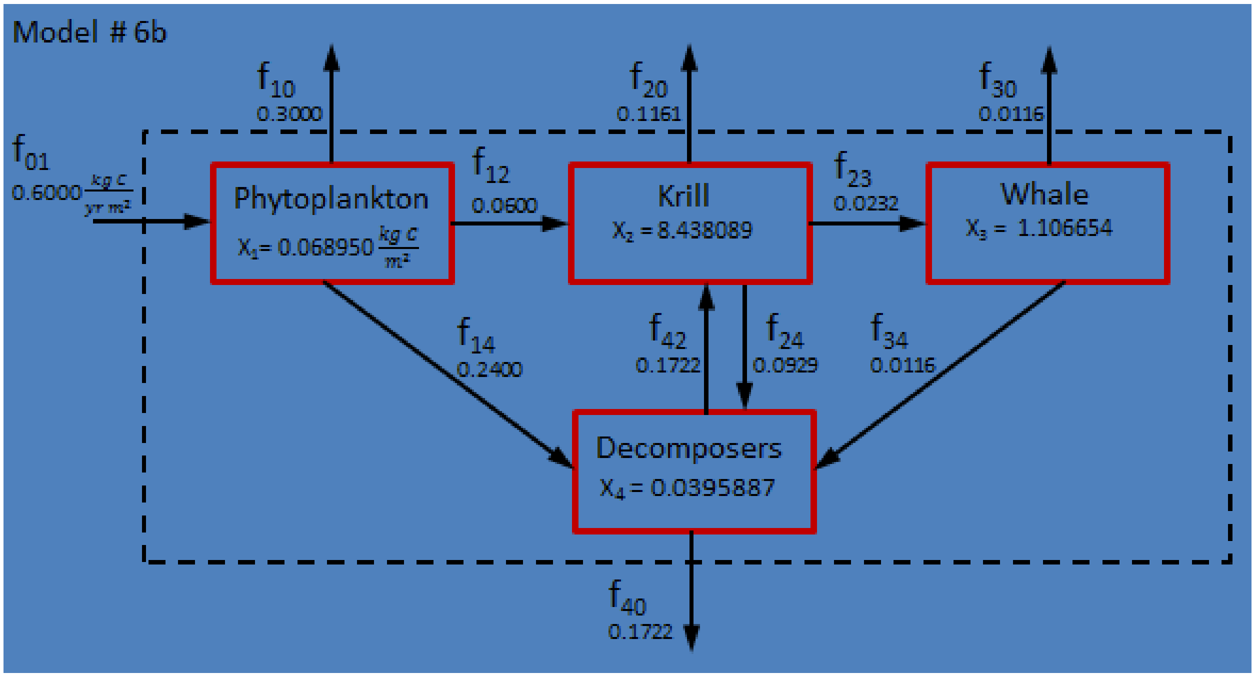

Model # 3
f_{10} 0.54000
f_{20} 0.05400
f_{30} 0.00540
f_{40} 0.00054
f_{50} 0.00006
f_{01} 0.6000 $\frac{kg\,c}{yr\,m^2}$
Phyto X_1= 0.020874
f_{12} 0.06000
Zoo X_2 = 0.020874
f_{23} 0.00600
Fish #1 X_3 = 0.020874
f_{34} 0.00060
Fish #2 X_4 = 0.020874
f_{45} 0.00006
Fish #3 X_5 = 0.020874

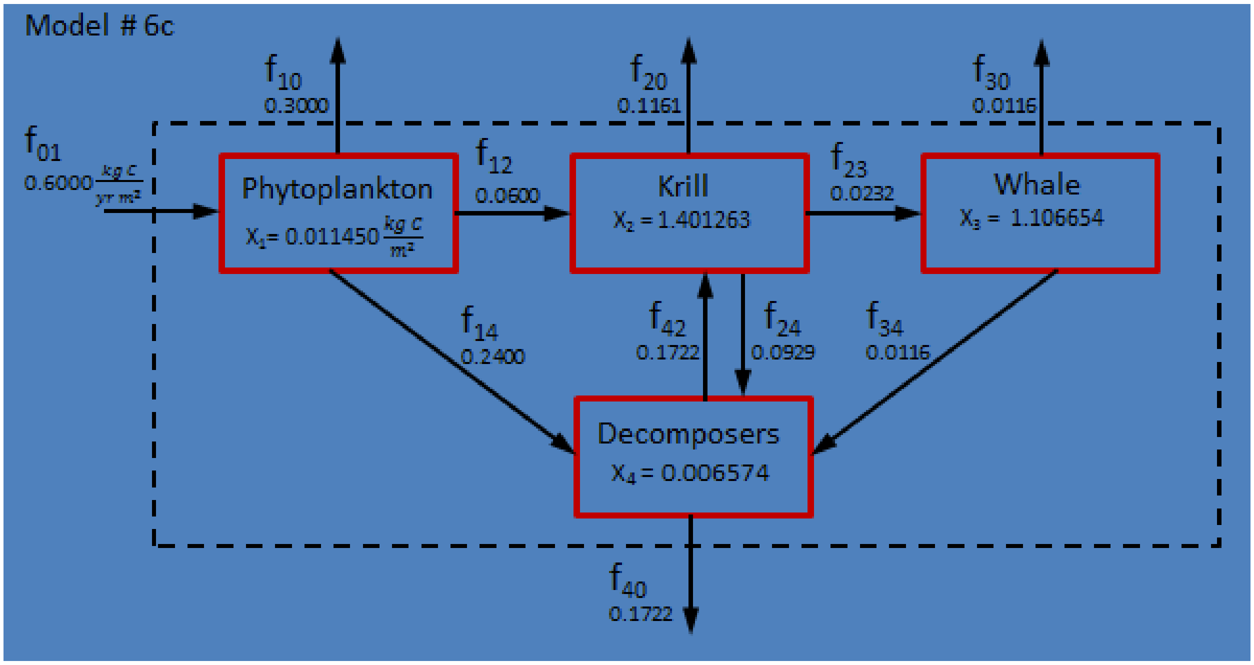

Model # 4a
f_{10} 0.3000
f_{20} 0.1157
f_{30} 0.01157
f_{40} 0.0012
f_{50} 0.00012
f_{01}=0.6000 $\frac{kg\,c}{yr\,m^2}$
Phyto X_1=0.0208739 $\frac{kg\,c}{m^2}$
f_{12} 0.0600
Zoo X_2 = 0.0805037
f_{23} 0.0231
Fish #1 X_3 = 0.0803646
f_{34} 0.00232
Fish #2 X_4 = 0.0800167
f_{45} 0.000232
Fish #3 X_5 = 0.0809560
f_{16} 0.240
f_{62} 0.1714
f_{26} 0.0926
f_{36} 0.009253
f_{46} 0.00093
f_{56} 0.00012
Decomposers X_6 = 0.0119294
f_{70} 0.1714

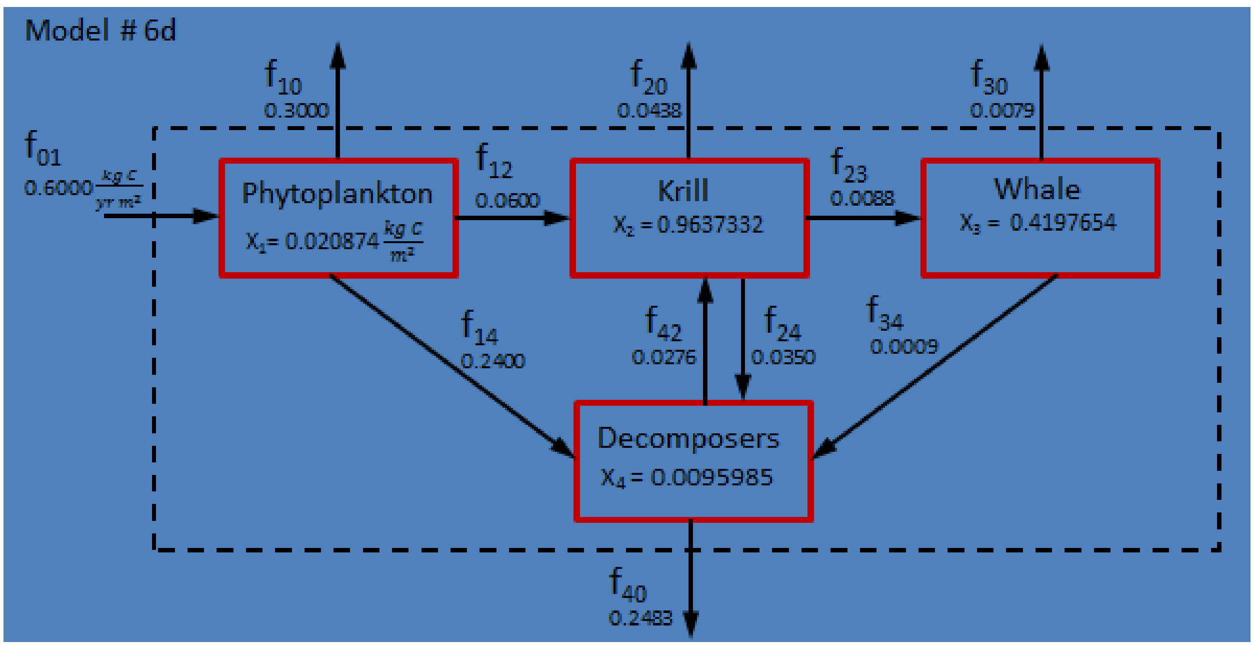

Model # 4b
f_{10} 0.0300
f_{20} 0.0044
f_{30} 0.00044
f_{40} 0.000044
f_{50} 0.0000044
f_{01}=0.0600 $\frac{kg\,c}{yr\,m^2}$
Phyto X_1=0.0020874 $\frac{kg\,c}{m^2}$
f_{12} 0.0060
Zoo X_2 = 0.0030615
f_{23} 0.00088
Fish #1 X_3 = 0.0030615
f_{34} 0.000088
Fish #2 X_4 = 0.0030615
f_{45} 0.0000088
Fish #3 X_5 = 0.0030615
f_{16} 0.024
f_{62} 0.0028
f_{26} 0.0035
f_{36} 0.00035
f_{46} 0.000035
f_{56} 0.0000044
Decomposers X_6 = 0.0009703
f_{70} 0.0251

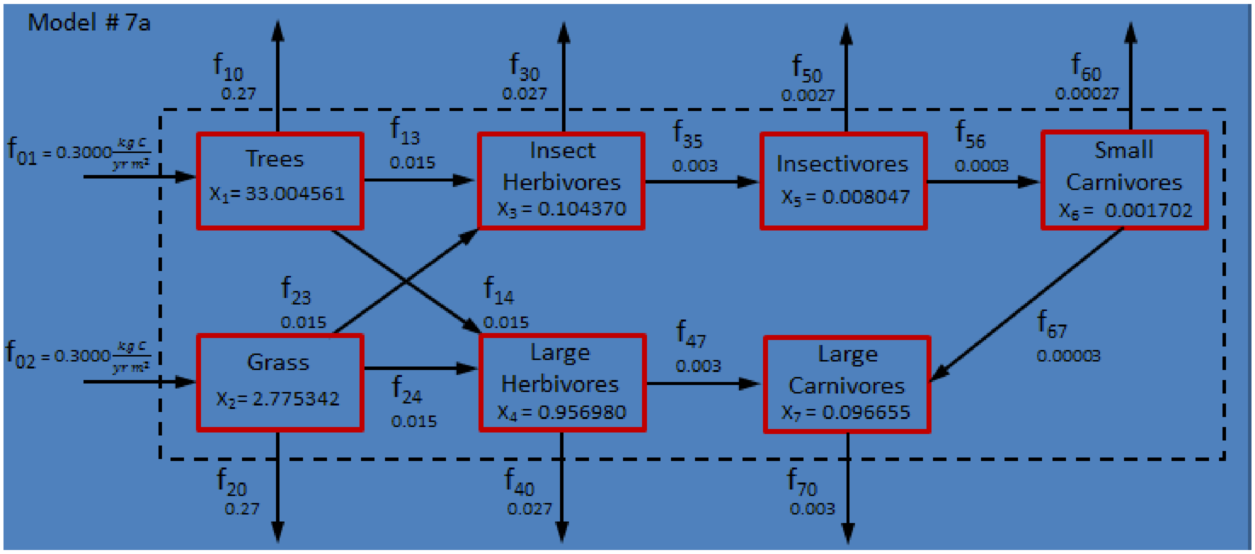

Model # 5
f_{10} 0.5400
f_{20} 0.0540
f_{30} 0.006
f_{01} 0.6000 $\frac{kg\,c}{yr\,m^2}$
Phytoplankton X_1= 0.020874 $\frac{kg\,c}{m^2}$
f_{12} 0.0600
Krill X_2 = 0.6600912
f_{23} 0.0060
Whale X_3 = 0.286204

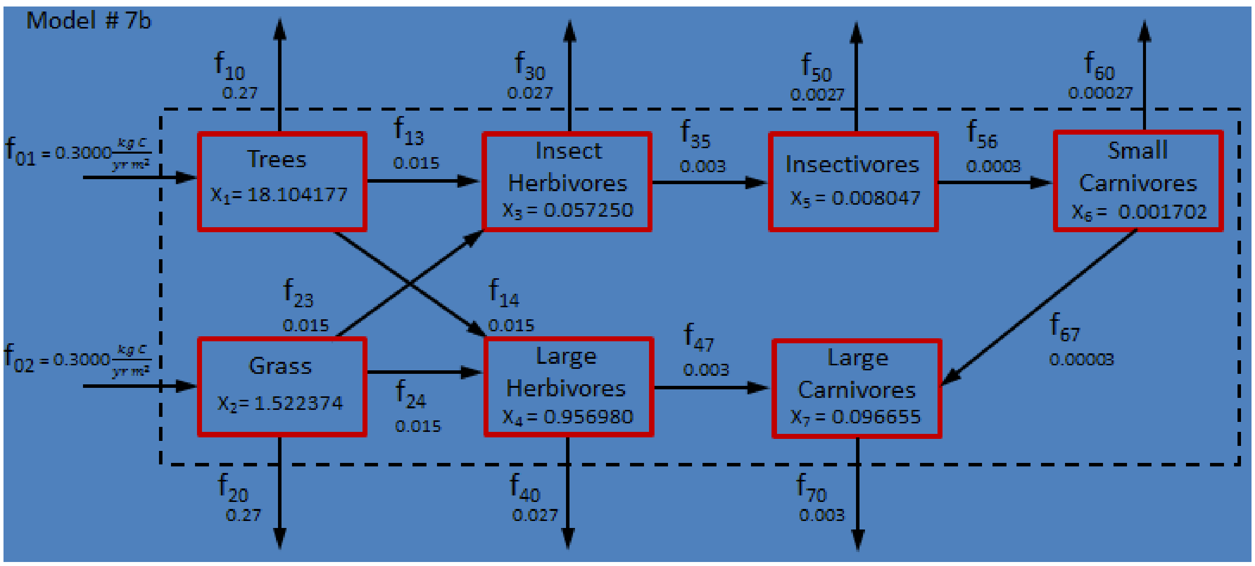

Model # 6a
f10
0.3000
f20
0.1161
f30
0.0116
f01
0.6000 kg C / yr m²
Phytoplankton
X1= 0.020874 kg C / m²
f12
0.0600
Krill
X2 = 2.554553
f23
0.0232
Whale
X3 = 1.106654
f14
0.2400
f42
0.1722
f24
0.0929
f34
0.0116
Decomposers
X4 = 0.0119851
f40
0.1722

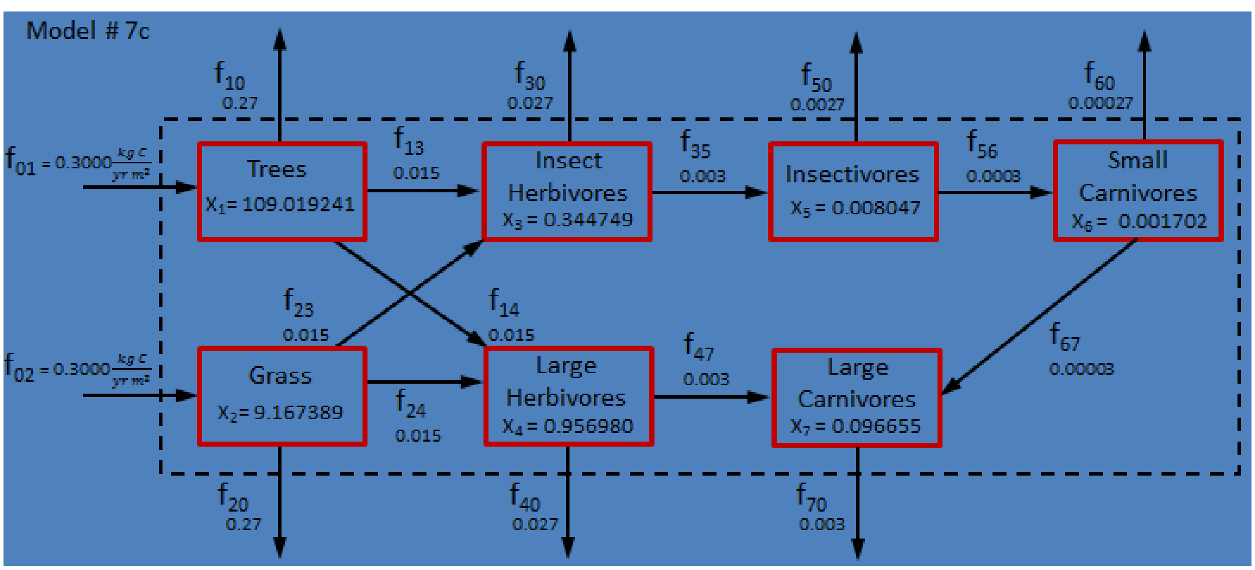

Model # 6b
f10
0.3000
f20
0.1161
f30
0.0116
f01
0.6000 kg C / yr m²
Phytoplankton
X1= 0.068950 kg C / m²
f12
0.0600
Krill
X2 = 8.438089
f23
0.0232
Whale
X3 = 1.106654
f14
0.2400
f42
0.1722
f24
0.0929
f34
0.0116
Decomposers
X4 = 0.0395887
f40
0.1722

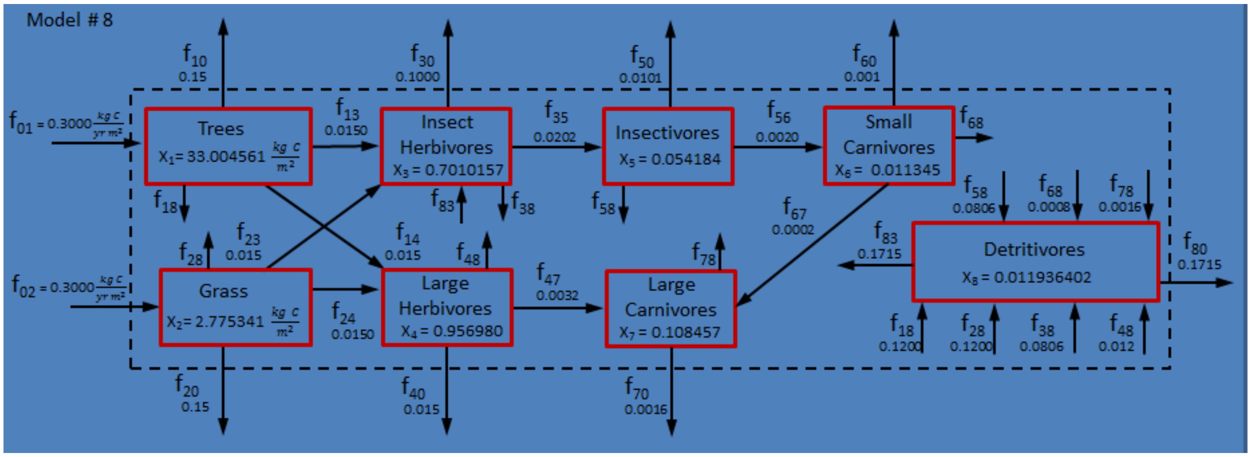

Model # 6c
f10
0.3000
f20
0.1161
f30
0.0116
f01
0.6000 kg C / yr m²
Phytoplankton
X1= 0.011450 kg C / m²
f12
0.0600
Krill
X2 = 1.401263
f23
0.0232
Whale
X3 = 1.106654
f14
0.2400
f42
0.1722
f24
0.0929
f34
0.0116
Decomposers
X4 = 0.006574
f40
0.1722


Model # 6d
f10
0.3000
f20
0.0438
f30
0.0079
f01
0.6000 kg C / yr m²
Phytoplankton
X1= 0.020874 kg C / m²
f12
0.0600
Krill
X2 = 0.9637332
f23
0.0088
Whale
X3 = 0.4197654
f14
0.2400
f42
0.0276
f24
0.0350
f34
0.0009
Decomposers
X4 = 0.0095985
f40
0.2483

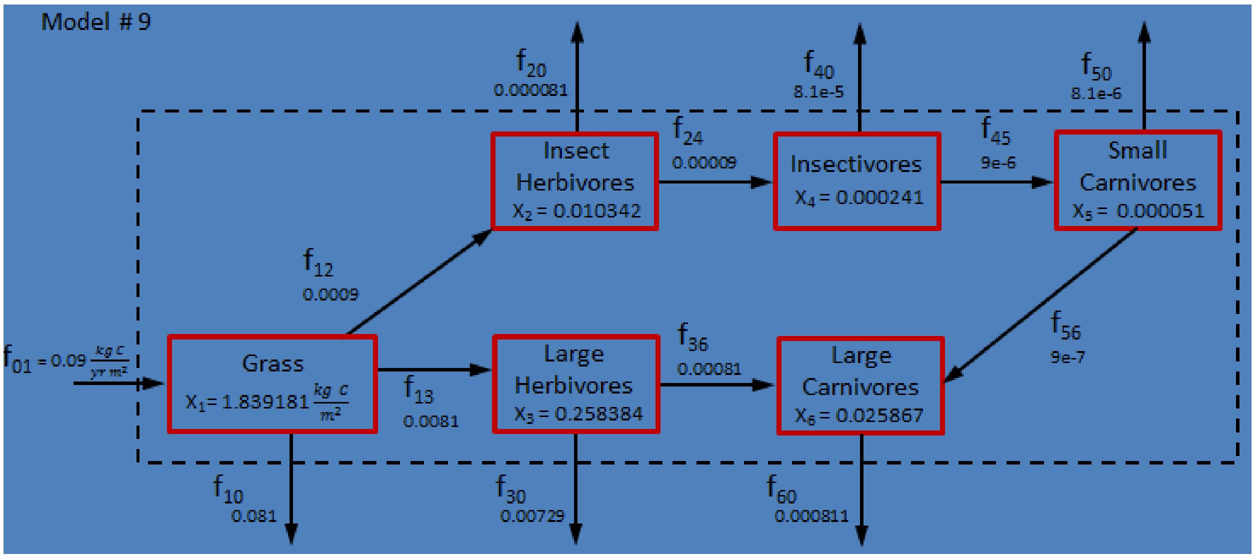

Model # 7a
f10 0.27
f30 0.027
f50 0.0027
f60 0.00027
f01 = 0.3000 kg C / yr m²
f02 = 0.3000 kg C / yr m²
Trees X1 = 33.004561
f13 0.015
Insect Herbivores X3 = 0.104370
f35 0.003
Insectivores X5 = 0.008047
f56 0.0003
Small Carnivores X6 = 0.001702
f23 0.015
f14 0.015
f47 0.003
f67 0.00003
Grass X2 = 2.775342
f24 0.015
Large Herbivores X4 = 0.956980
Large Carnivores X7 = 0.096655
f20 0.27
f40 0.027
f70 0.003


Model # 7b
f10 0.27
f30 0.027
f50 0.0027
f60 0.00027
f01 = 0.3000 kg C / yr m²
f02 = 0.3000 kg C / yr m²
Trees X1 = 18.104177
f13 0.015
Insect Herbivores X3 = 0.057250
f35 0.003
Insectivores X5 = 0.008047
f56 0.0003
Small Carnivores X6 = 0.001702
f23 0.015
f14 0.015
f47 0.003
f67 0.00003
Grass X2 = 1.522374
f24 0.015
Large Herbivores X4 = 0.956980
Large Carnivores X7 = 0.096655
f20 0.27
f40 0.027
f70 0.003

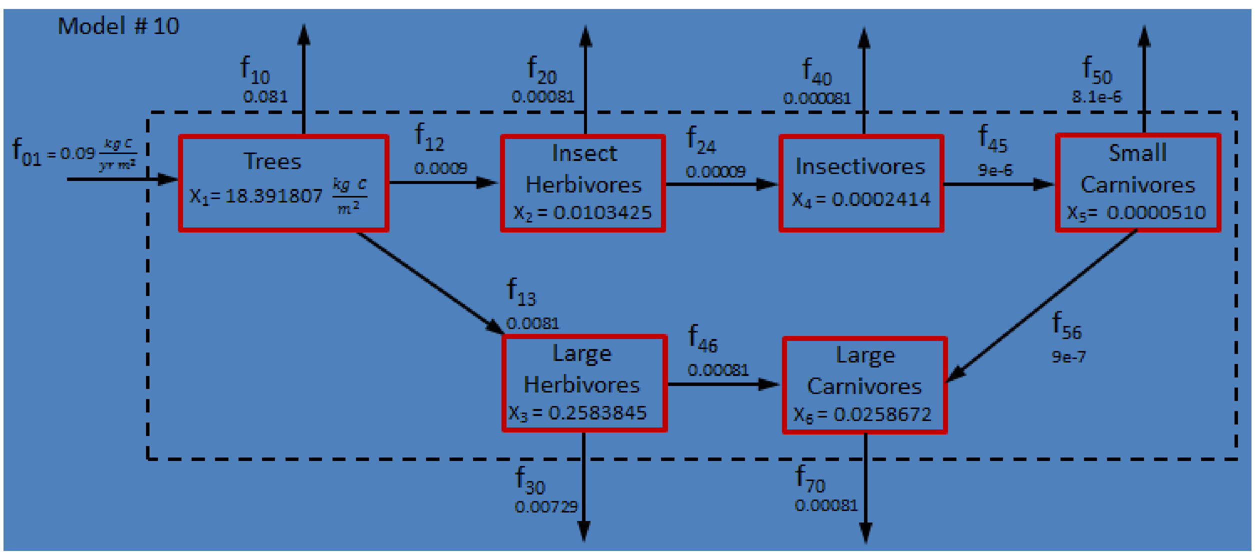

Model # 7c
f10 0.27
f30 0.027
f50 0.0027
f60 0.00027
f01 = 0.3000 kg C / yr m²
f02 = 0.3000 kg C / yr m²
Trees X1 = 109.019241
f13 0.015
Insect Herbivores X3 = 0.344749
f35 0.003
Insectivores X5 = 0.008047
f56 0.0003
Small Carnivores X6 = 0.001702
f23 0.015
f14 0.015
f47 0.003
f67 0.00003
Grass X2 = 9.167389
f24 0.015
Large Herbivores X4 = 0.956980
Large Carnivores X7 = 0.096655
f20 0.27
f40 0.027
f70 0.003



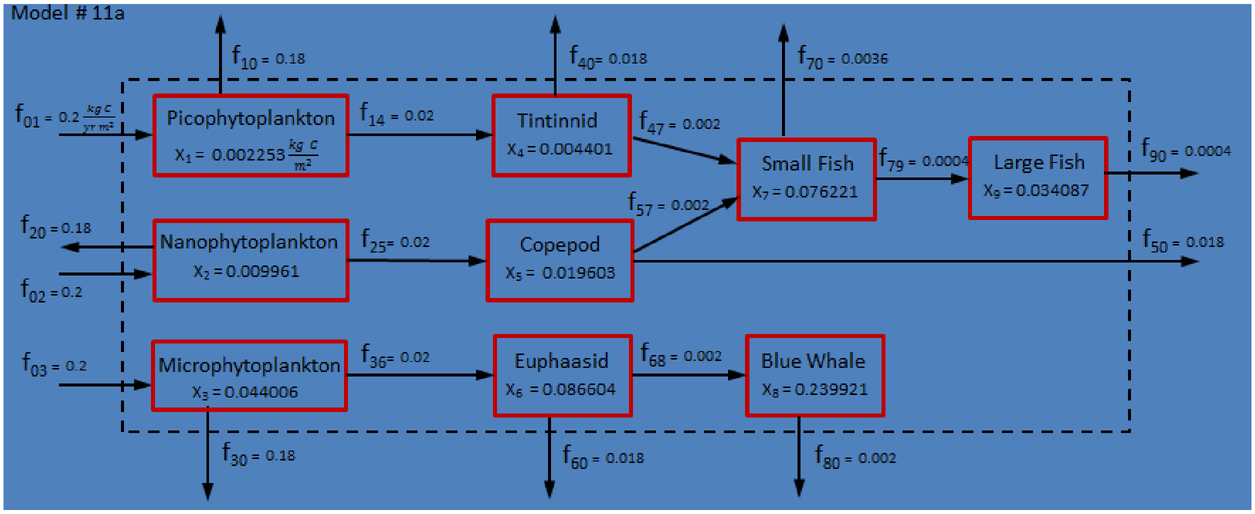
Model # 8
f10
0.15
f30
0.1000
f50
0.0101
f60
0.001
f01 = 0.3000 kg c / yr m²
Trees
X1= 33.004561 kg c / m²
f13
0.0150
Insect
Herbivores
X3 = 0.7010157
f35
0.0202
Insectivores
X5 = 0.054184
f56
0.0020
Small
Carnivores
X6 = 0.011345
f68
f18
f83
f38
f58
f67
0.0002
f58
0.0806
f68
0.0008
f78
0.0016
f28
f23
0.015
f14
0.015
f48
f78
f83
0.1715
Detritivores
X8 = 0.011936402
f80
0.1715
f02 = 0.3000 kg c / yr m²
Grass
X2= 2.775341 kg c / m²
f24
0.0150
Large
Herbivores
X4 = 0.956980
f47
0.0032
Large
Carnivores
X7 = 0.108457
f18
0.1200
f28
0.1200
f38
0.0806
f48
0.012
f20
0.15
f40
0.015
f70
0.0016



Model # 9
f20
0.000081
f40
8.1e-5
f50
8.1e-6
f24
0.00009
f45
9e-6
Insect
Herbivores
X2 = 0.010342
Insectivores
X4 = 0.000241
Small
Carnivores
X5 = 0.000051
f12
0.0009
f56
9e-7
f01 = 0.09 kg c / yr m²
Grass
X1= 1.839181 kg c / m²
f13
0.0081
Large
Herbivores
X3 = 0.258384
f36
0.00081
Large
Carnivores
X6 = 0.025867
f10
0.081
f30
0.00729
f60
0.000811



Model # 10
f10
0.081
f20
0.00081
f40
0.000081
f50
8.1e-6
f01 = 0.09 kg c / yr m²
Trees
X1= 18.391807 kg c / m²
f12
0.0009
Insect
Herbivores
X2 = 0.0103425
f24
0.00009
Insectivores
X4 = 0.0002414
f45
9e-6
Small
Carnivores
X5= 0.0000510
f13
0.0081
f56
9e-7
Large
Herbivores
X3 = 0.2583845
f46
0.00081
Large
Carnivores
X6 = 0.0258672
f30
0.00729
f70
0.00081


Model # 11a
f10 = 0.18
f40= 0.018
f70 = 0.0036
f01 = 0.2 kg C / yr m²
Picophytoplankton
X1 = 0.002253 kg C / m²
f14 = 0.02
Tintinnid
X4 = 0.004401
f47 = 0.002
Small Fish
X7 = 0.076221
f79 = 0.0004
Large Fish
X9 = 0.034087
f90 = 0.0004
f20 = 0.18
Nanophytoplankton
X2 = 0.009961
f02 = 0.2
f25= 0.02
Copepod
X5 = 0.019603
f57 = 0.002
f50 = 0.018
f03 = 0.2
Microphytoplankton
X3 = 0.044006
f36= 0.02
Euphaasid
X6 = 0.086604
f68 = 0.002
Blue Whale
X8 = 0.239921
f30 = 0.18
f60 = 0.018
f80 = 0.002