Main text figures: The benefits and consequences of predator-mediated mutualisms

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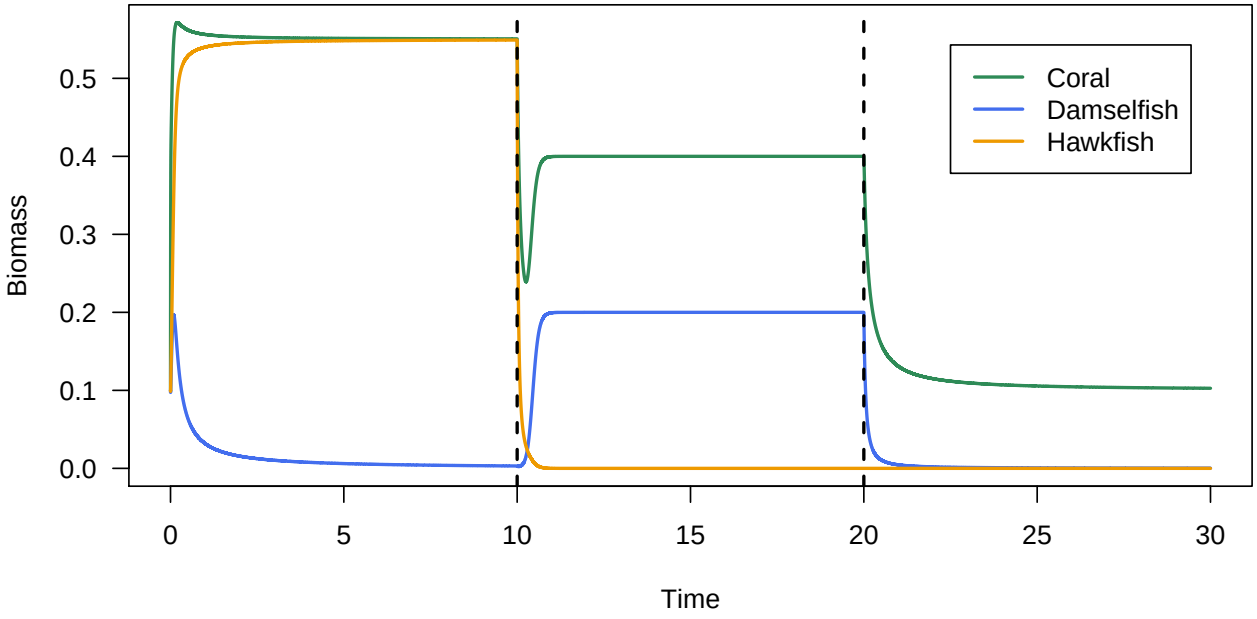
5 May 2021

Figure 2: Timeseries of changing predator abundances.



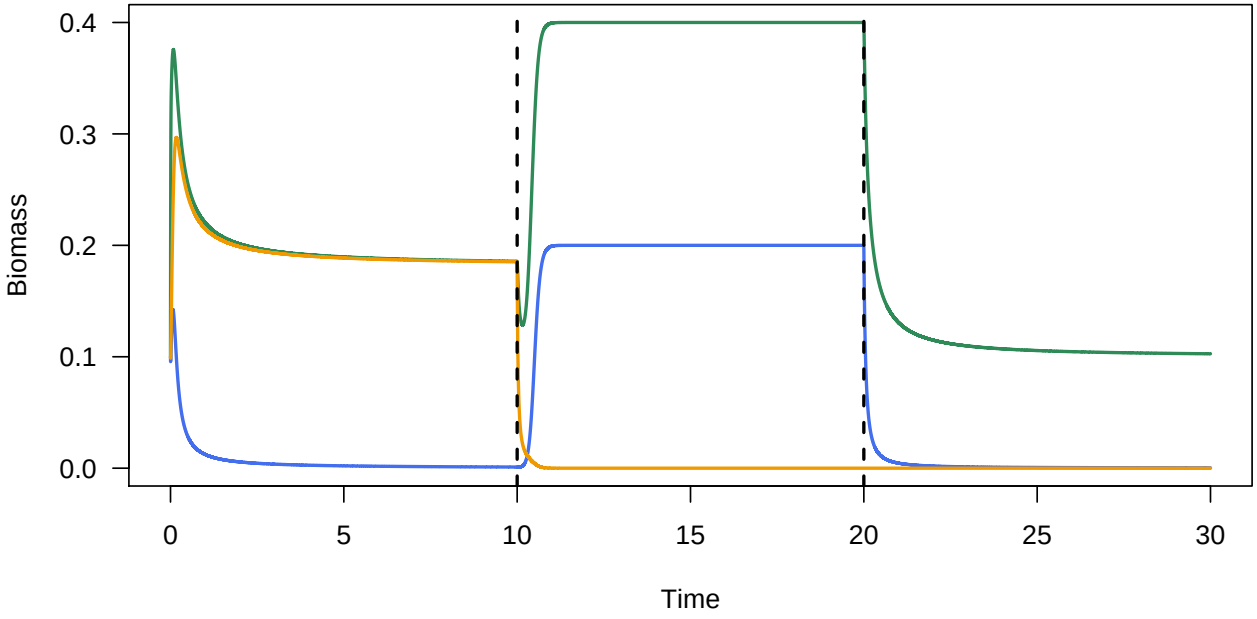


Figure 3: Heatmaps of coral biomass as a function of predators and parameters.

Simulations varying alpha and predator abundance:

```
### Chunk is time-consuming to run. Un-comment to run; otherwise this code relies on saved data from a p

# phi <- 2
# epsilon <- 0.5
#
# pmax <- rho_D*(1-epsilon*k_H/k_D)
#
# alphaset <- seq(from = 0, to = 1, length.out = 105)
# Pset <- seq(from = 0, to = pmax, length.out = 100)
#
# cstar <- matrix(rep(NaN,length(alphaset)*length(Pset)),nrow = length(alphaset),ncol = length(Pset))
# dstar <- cstar
# hstar <- cstar
#
# t_end <- 365*2*10;
# tset <- seq(from=0, to = t_end, length.out = 10*t_end)
#
# for(k in 1:length(alphaset)){
#   alpha <- alphaset[k]
# for(j in 1:length(Pset)){
#   p <- Pset[j]
# d.simu1 <- NaN*tset; d.simu1[1] <- 0.5;
# h.simu1 <- d.simu1;
# c.simu1 <- d.simu1;
# for(i in 2:length(tset)){
#   dt <- tset[i]-tset[i-1]
#   d <- d.simu1[i-1]
#   h <- h.simu1[i-1]
#   c <- c.simu1[i-1]
#   dc <- ((c+d+epsilon*h)*(1-c)-mu*c)*dt
#   dd <- (rho_D*d*(k_D*c-d-h)/(k_D*c)-d*p)*dt
#   dh <- (rho_H*h*(k_H*c-h-alpha*d)/(k_H*c)-phi*h*p)*dt
#   c.simu1[i] <- c+dc
#   d.simu1[i] <- d+dd
#   h.simu1[i] <- h+dh
# }
#   dstar[k,j] <- d.simu1[length(tset)];
#   hstar[k,j] <- h.simu1[length(tset)];
#   cstar[k,j] <- c.simu1[length(tset)];
# }}
#
#
# dstar_a <- dstar
# hstar_a <- hstar
# cstar_a <- cstar
```

Simulations varying phi and predator abundance:

```
### Chunk is time-consuming to run. Un-comment to run; otherwise this code relies on saved data from a p

# alpha <- 0.5
# epsilon <- 0.5
#
# pmax <- rho_D*(1-epsilon*k_H/k_D)
```

```
#
# phiset <- seq(from = 1, to = 10, length.out = 105)
# Pset <- seq(from = 0, to = pmax, length.out = 100)
#
# cstar <- matrix(rep(NaN,length(phiset)*length(Pset)),nrow = length(phiset),ncol = length(Pset))
# dstar <- cstar
# hstar <- cstar
#
# t_end <- 365*2*10;
# tset <- seq(from=0, to = t_end, length.out = 10*t_end)
#
# for(k in 1:length(phiset)){
#   phi <- phiset[k]
# for(j in 1:length(Pset)){
#   p <- Pset[j]
# d.simu1 <- NaN*tset; d.simu1[1] <- 0.5;
# h.simu1 <- d.simu1;
# c.simu1 <- d.simu1;
# for(i in 2:length(tset)){
#   dt <- tset[i]-tset[i-1]
#   d <- d.simu1[i-1]
#   h <- h.simu1[i-1]
#   c <- c.simu1[i-1]
#   dc <- ((c+d+epsilon*h)*(1-c)-mu*c)*dt
#   dd <- (rho_D*d*(k_D*c-d-h)/(k_D*c)-d*p)*dt
#   dh <- (rho_H*h*(k_H*c-h-alpha*d)/(k_H*c)-phi*h*p)*dt
#   c.simu1[i] <- c+dc
#   d.simu1[i] <- d+dd
#   h.simu1[i] <- h+dh
# }
#   dstar[k,j] <- d.simu1[length(tset)];
#   hstar[k,j] <- h.simu1[length(tset)];
#   cstar[k,j] <- c.simu1[length(tset)];
# }}
#
#
#
# dstar_p <- dstar
# hstar_p <- hstar
# cstar_p <- cstar
```

Simulations varying epsilon and predator abundance:

```
### Chunk is time-consuming to run. Un-comment to run; otherwise this code relies on saved data from a p

# alpha <- 0.5
# phi <- 2
#
# pmax <- rho_D*(1-0*k_H/k_D)
#
# epsilonset <- seq(from = 0, to = 1, length.out = 105)
# Pset <- seq(from = 0, to = pmax, length.out = 100)
#
# cstar <- matrix(rep(NaN,length(epsilonset)*length(Pset)),nrow = length(epsilonset),ncol = length(Pset
```

```
# dstar <- cstar
# hstar <- cstar
#
# t_end <- 365*2*10;
# tset <- seq(from=0, to = t_end, length.out = 20*t_end)
#
# for(k in 1:length(epsilonset)){
#   epsilon <- epsilonset[k]
# for(j in 1:length(Pset)){
#   p <- Pset[j]
# d.simu1 <- NaN*tset; d.simu1[1] <- 0.5;
# h.simu1 <- d.simu1;
# c.simu1 <- d.simu1;
# for(i in 2:length(tset)){
#   dt <- tset[i]-tset[i-1]
#   d <- d.simu1[i-1]
#   h <- h.simu1[i-1]
#   c <- c.simu1[i-1]
#   dc <- ((c+d+epsilon*h)*(1-c)-mu*c)*dt
#   dd <- (rho_D*d*(k_D*c-d-h)/(k_D*c)-d*p)*dt
#   dh <- (rho_H*h*(k_H*c-h-alpha*d)/(k_H*c)-phi*h*p)*dt
#   c.simu1[i] <- c+dc
#   d.simu1[i] <- d+dd
#   h.simu1[i] <- h+dh
# }
#   dstar[k,j] <- d.simu1[length(tset)];
#   hstar[k,j] <- h.simu1[length(tset)];
#   cstar[k,j] <- c.simu1[length(tset)];
# }}
#
#
# dstar_e <- dstar
# hstar_e <- hstar
# cstar_e <- cstar
```

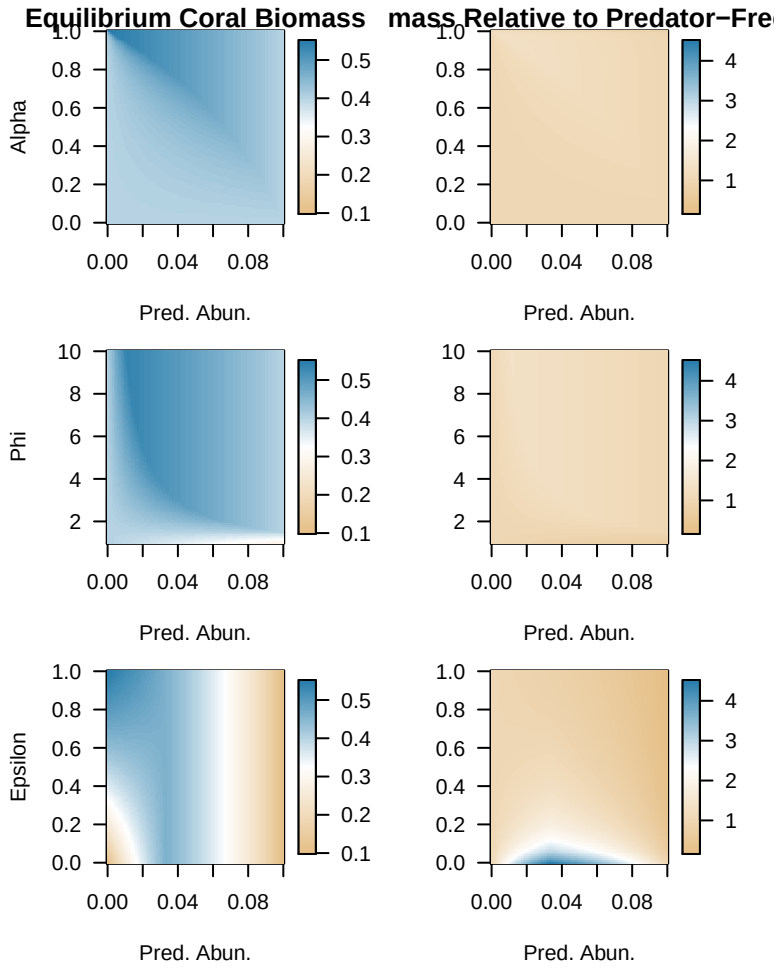
```
# setwd('/Users/hollyvm/Box Sync/StierMoeller_PredMedMutualisms/Code/RCodes')

# save(dstar_a,hstar_a,cstar_a,dstar_p,hstar_p,cstar_p,dstar_e,hstar_e,cstar_e,Pset,epsilonset,phiset,a
```

Load results

```
setwd('/Users/hollyvm/Box Sync/StierMoeller_PredMedMutualisms/Code/RCodes')

#load('Heatmap1.Rdata') #low resolution: 20 x 25
load('Heatmap3.Rdata') #high resolution: 100 x 105
```

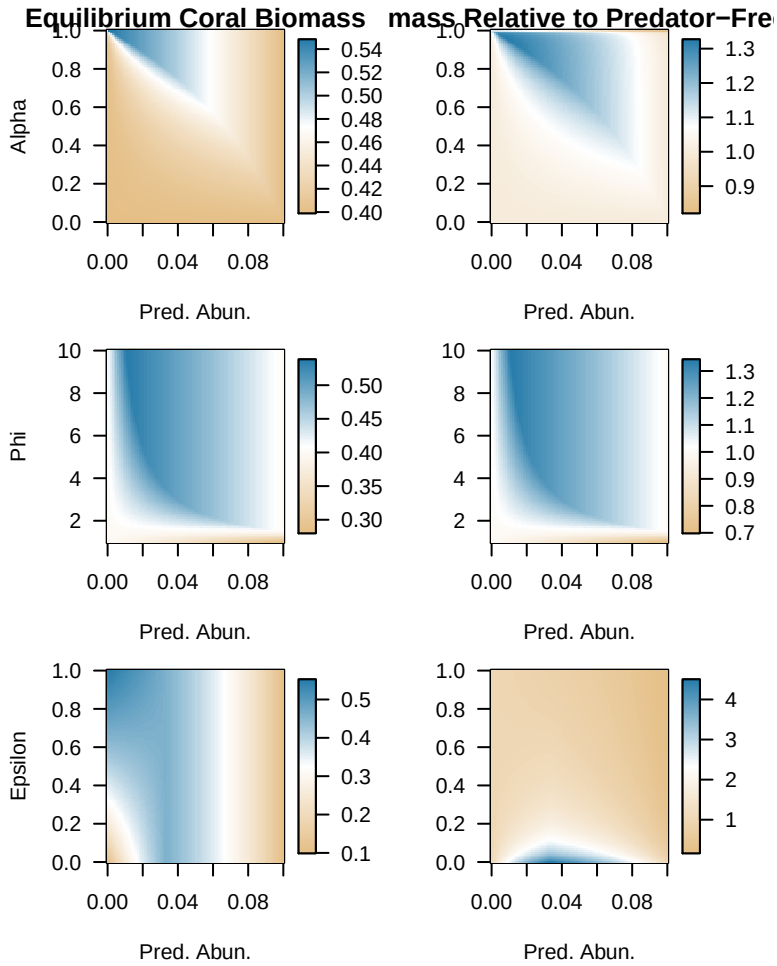
```
kot <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

rwb <- kot

zlimraw <- c(0.1,.55)
zlimrel <- c(.18,4.5)

par(mar=c(4,4,1,1),mfrow=c(3,2))
```

```
#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r


image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',zli
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:length(Pset)] <- cstar_a[i,1:length(Pset)]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(relcstar_a),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.',zlim=

image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.',zlim=zl
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
  relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
}
image.plot(x = Pset, y = phiset, z = t(relcstar_p),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.',zlim=zl


image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun.
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
}
image.plot(x = Pset, y = epsilonset, z = t(relcstar_e),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.',zli
```



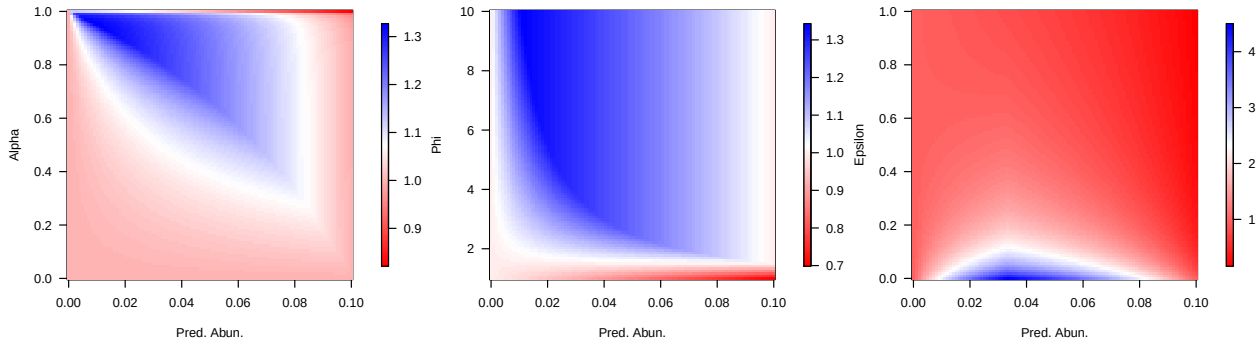

```
kot <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

rwb <- kot


par(mar=c(4,4,1,1),mfrow=c(3,2))

#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r


image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',ma
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:(dim(relcstar_a)[2])] <- cstar_a[i,1:(dim(relcstar_a)[2])]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(relcstar_a),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.',main=

image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
  #relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
  relcstar_p[i,1:(dim(relcstar_p)[2])] <- cstar_p[i,1:(dim(relcstar_p)[2])]/cstar_p[i,1]
```

```
}
image.plot(x = Pset, y = phiset, z = t(relcstar_p),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.');


image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun.
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  #relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
  relcstar_e[i,1:(dim(relcstar_e)[2])] <- cstar_e[i,1:(dim(relcstar_e)[2])]/cstar_e[i,1]
}
image.plot(x = Pset, y = epsilonset, z = t(relcstar_e),las=1,col=rwb(100),ylab='',xlab='Pred. Abun.')
```



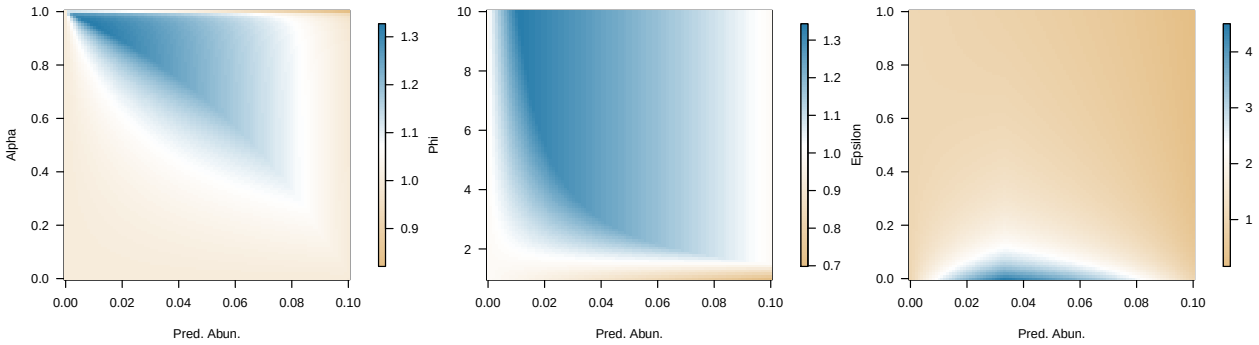

```
kot <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

#rwb <- kot


par(mar=c(4,4,1,5),mfrow=c(1,3))

#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r
```

```
#image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',m
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:length(Pset)] <- cstar_a[i,1:length(Pset)]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(relcstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.')

#image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
  relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
}
image.plot(x = Pset, y = phiset, z = t(relcstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');


#image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
}
image.plot(x = Pset, y = epsilonset, z = t(relcstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abu
```



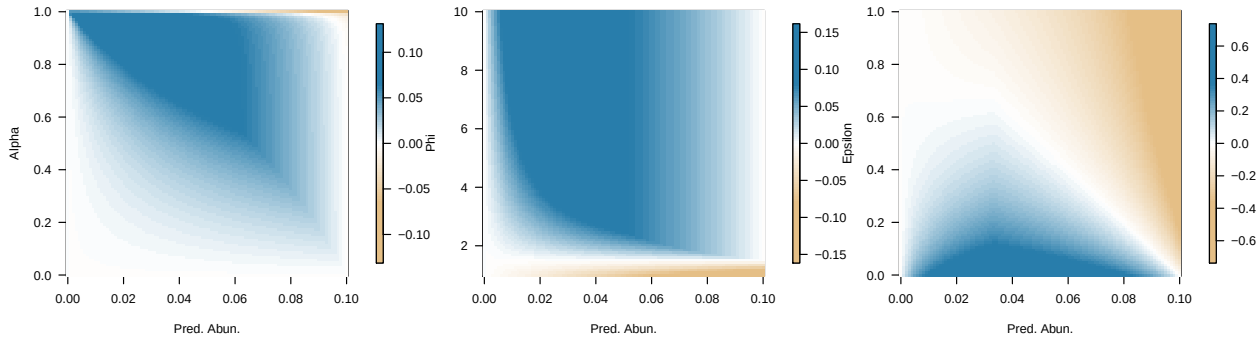

```
kot <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

rwb <- kot


par(mar=c(4,4,1,5),mfrow=c(1,3))

#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r


#image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',m
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:length(Pset)] <- cstar_a[i,1:length(Pset)]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(relcstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.')

#image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
```

```
  relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
}
image.plot(x = Pset, y = phiset, z = t(relcstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');


#image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
}
image.plot(x = Pset, y = epsilonset, z = t(relcstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abu
```

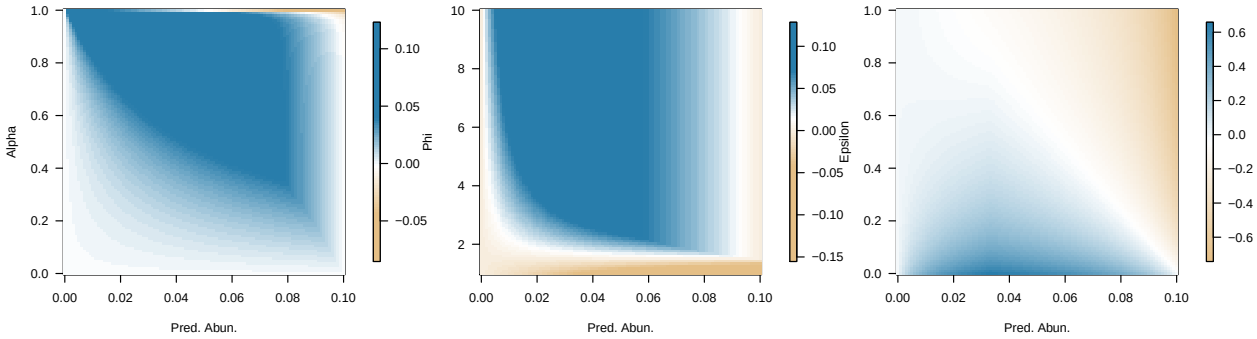



```
kot <- colorRampPalette(colors = c(kotare[3],kotare[3],'white',kotare[2],kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

rwb <- kot


par(mar=c(4,4,1,5),mfrow=c(1,3))

#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r


#image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',m
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:length(Pset)] <- cstar_a[i,1:length(Pset)]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(log10(relcstar_a)),las=1,col=rwb(100),ylab='Alpha',xlab='Pred.

#image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
  relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
}
image.plot(x = Pset, y = phiset, z = t(log10(relcstar_p)),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abu


#image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
}
```

```
image.plot(x = Pset, y = epsilonset, z = t(log10(relcstar_e)),las=1,col=rwb(100),ylab='Epsilon',xlab='P
```




```
kot <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))
rwb <- colorRampPalette(colors = c("red", "white", "blue"))

rwb <- kot


par(mar=c(4,4,1,5),mfrow=c(1,3))

#panelwidths = 2; panelheights = 2; layout(matrix(c(rep(7,1+2*panelwidths),rep(c(8,rep(1,panelwidths),r

rwb <- colorRampPalette(colors = c(kotare[3],kotare[3],'white',kotare[2],kotare[2],kotare[2]))

#image.plot(x = Pset, y = alphaset, z = t(cstar_a),las=1,col=rwb(100),ylab='Alpha',xlab='Pred. Abun.',m
relcstar_a <- cstar_a*NaN
for(i in 1:length(alphaset)){
  relcstar_a[i,1:length(Pset)] <- cstar_a[i,1:length(Pset)]/cstar_a[i,1]
}
image.plot(x = Pset, y = alphaset, z = t(log10(relcstar_a)),las=1,col=rwb(100),ylab='Alpha',xlab='Pred.

rwb <- colorRampPalette(colors = c(kotare[3],kotare[3],kotare[3],'white',kotare[2],kotare[2]))
#rwb <- colorRampPalette(colors = c(kotare[3],kotare[3],kotare[3],kotare[3],'white',kotare[2],kotare[2]

#image.plot(x = Pset, y = phiset, z = t(cstar_p),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abun.');
relcstar_p <- cstar_p*NaN
for(i in 1:length(phiset)){
  relcstar_p[i,1:length(Pset)] <- cstar_p[i,1:length(Pset)]/cstar_p[i,1]
}
image.plot(x = Pset, y = phiset, z = t(log10(relcstar_p)),las=1,col=rwb(100),ylab='Phi',xlab='Pred. Abu


rwb <- colorRampPalette(colors = c(kotare[3],'white',kotare[2]))

#image.plot(x = Pset, y = epsilonset, z = t(cstar_e),las=1,col=rwb(100),ylab='Epsilon',xlab='Pred. Abun
relcstar_e <- cstar_e*NaN
for(i in 1:length(epsilonset)){
  relcstar_e[i,1:length(Pset)] <- cstar_e[i,1:length(Pset)]/cstar_e[i,1]
}
image.plot(x = Pset, y = epsilonset, z = t(log10(relcstar_e)),las=1,col=rwb(100),ylab='Epsilon',xlab='P
```


Alpha
Pred. Abun.
Phi
Pred. Abun.
Epsilon
Pred. Abun.