Appendix for: Deep Reinforcement Learning for Conservation Decisions

A Preprint

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April 7, 2021

Abstract

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***K*eywords** blah · blee · bloo · these are optional and can be removed

```
library(tidyverse)
library(patchwork)
library(reticulate)

np <- import("numpy")
np$random$seed(42L)

# force CPU-evaluation if needing perfect reproducibility
Sys.setenv("CUDA_VISIBLE_DEVICES"="0")
```

1 Finding a known optimal solution using RL

1.1 Sustainable Harvest Quotas

```
## Python dependencies
gym         <- import ("gym")
gym_fishing <- import("gym_fishing")
sb3         <- import ("stable_baselines3")

## initialize the environment
env <- gym$make("fishing-v1", sigma = 0.1)
```

```
# train an agent (model) on one of the environments:


#Trial 15 finished with value: 7.6994757652282715 and parameters:
hyper = list('gamma'= 0.995, 'lr'= 0.0001355522450968401, 'batch_size'= 128L,
         'buffer_size'= 10000L, 'episodic'= FALSE, 'train_freq'= 128L,
         'noise_type'= 'normal', 'noise_std'= 0.6656948079225263,
         'net_arch'= 'big')
policy_kwargs = list(net_arch=c(400L, 300L)) # big


#non-episodic:
hyper['gradient_steps'] = hyper['train_freq']
hyper['n_episodes_rollout'] = -1
n_actions = env$action_space$shape[0]
hyper$action_noise = sb3$common$noise$NormalActionNoise(
        mean=np$zeros(n_actions),
        sigma= hyper[['noise_std']] * np$ones(n_actions)
        )


td3 = sb3$TD3('MlpPolicy', env,  verbose=0L, seed = 42L,
            gamma = hyper[['gamma']],
            learning_rate = hyper[['lr']],
            batch_size = hyper[['batch_size']],
            buffer_size = hyper[['buffer_size']],
            action_noise = hyper[['action_noise']],
            train_freq = hyper[['train_freq']],
            gradient_steps = hyper[['train_freq']],
            n_episodes_rollout = hyper[['n_episodes_rollout']],
            policy_kwargs=policy_kwargs)


td3$learn(total_timesteps=300000L)
td3$save("cache/td3")
```

```
# Simulate management under the trained agent
td3 <- sb3$TD3$load("cache/td3")
td3_sims <- env$simulate(td3, reps = 500L)
td3_policy <- env$policyfn(td3, reps = 50L)
```

```
# train an agent (model) on one of the environments:
a2c <- sb3$A2C('MlpPolicy', env, verbose=0L, seed = 42L) # Must use L for integers!
a2c$learn(total_timesteps=300000L)
a2c$save("cache/a2c")
```

```
# Simulate management under the trained agent
a2c <- sb3$A2C$load("cache/a2c")
```

```
a2c_sims <- env$simulate(a2c, reps = 500L)
a2c_policy <- env$policyfn(a2c, reps = 50L)
```

```
# Simulate under the optimal solution (given the model)
opt <- gym_fishing$models$escapement(env)
opt_sims <- env$simulate(opt, reps = 500L)
opt_policy <- env$policyfn(opt)
```

```
sims_df <- bind_rows(td3_sims, a2c_sims, opt_sims, .id = "model") %>%
  mutate(model = c("TD3", "A2C", "optimal")[as.integer(model)])

policy_df <- bind_rows(td3_policy, a2c_policy, opt_policy, .id = "model") %>%
  mutate(model = c("TD3", "A2C", "optimal")[as.integer(model)])

gamma <- 1 #discount
reward_df <- sims_df %>%
  group_by(rep, model) %>%
  mutate(cum_reward = cumsum(reward * gamma^time)) %>%
  group_by(time, model) %>%
  summarise(mean_reward = mean(cum_reward),
            sd = sd(cum_reward), .groups = "drop")
```

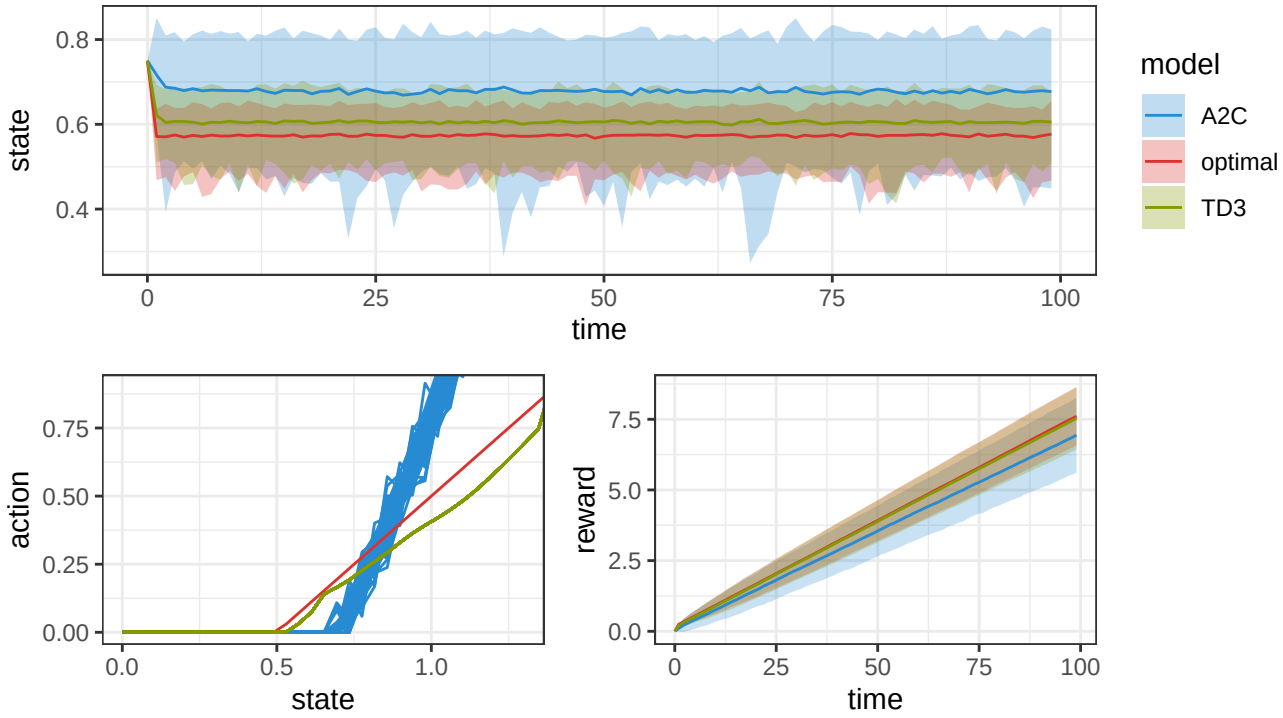
```
write_csv(sims_df, "figs/sims_df.csv")
write_csv(policy_df, "figs/policy_df.csv")
write_csv(reward_df, "figs/reward_df.csv")
```

```
ymin <- function(x) last(x[(ntile(x, 20)==1)])
ymax <- function(x) last(x[(ntile(x, 20)==19)])

fig_sims <-
sims_df %>%
  group_by(time, model) %>%
  summarise(ymin = ymin(state),
            ymax = ymax(state),
            state = mean(state), .groups = "drop") %>%
  ggplot(aes(time, state, ymin = ymin, ymax = ymax, fill=model)) +
  geom_ribbon(alpha= 0.3) + geom_line(aes(col = model))
```

```
fig_policy <-
  policy_df %>% ggplot(aes(state, action,
                           group=interaction(rep, model),
                           col = model)) +
  geom_line(show.legend = FALSE) +
  coord_cartesian(xlim = c(0, 1.3), ylim=c(0,0.9))
```

```
fig_reward <- reward_df %>%
  ggplot(aes(time, mean_reward)) +
  geom_ribbon(aes(ymin = mean_reward - 2*sd,
                  ymax = mean_reward + 2*sd, fill = model),
              alpha=0.25, show.legend = FALSE) +
  geom_line(aes(col = model), show.legend = FALSE) +
  ylab("reward")
```

```
fig_sims / ( fig_policy + fig_reward)
```



1.2 Ecological tipping points

```
gym_conservation <- import("gym_conservation")
env <- gym$make("conservation-v6")
```

```
# Simulate management under the trained agent
TD3 <- sb3$TD3$load("cache/td3-conservation")
TD3_sims <- env$simulate(TD3, reps = 100L)
TD3_policy <- env$policyfn(TD3, reps = 10L)
```

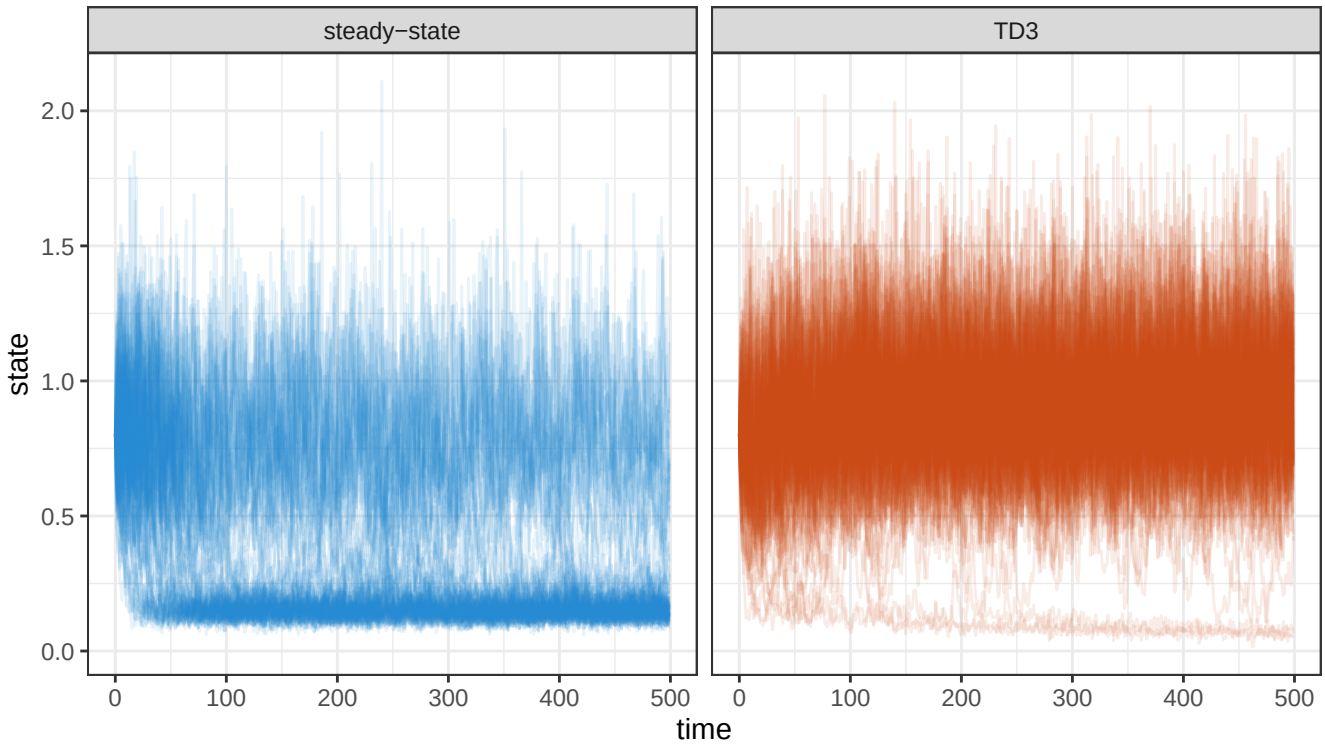
```
# Simulate under the steady-state solution (given the model)
K = 1.5
alpha = 0.001
opt <- gym_conservation$models$fixed_action(env, fixed_action = alpha * 100 * 2 * K )
opt_sims <- env$simulate(opt, reps = 100L)
opt_policy <- env$policyfn(opt)
```

```
sims_df <- bind_rows(TD3_sims, opt_sims, .id = "model") %>%
  mutate(model = c("TD3", "steady-state")[as.integer(model)])

policy_df <- bind_rows(TD3_policy, opt_policy, .id = "model") %>%
  mutate(model = c("TD3", "steady-state")[as.integer(model)])

gamma <- 1 #discount
reward_df <- sims_df %>%
  group_by(rep, model) %>%
  mutate(cum_reward = cumsum(reward * gamma^time)) %>%
  group_by(time, model) %>%
  summarise(mean_reward = mean(cum_reward),
            sd = sd(cum_reward), .groups = "drop")
```

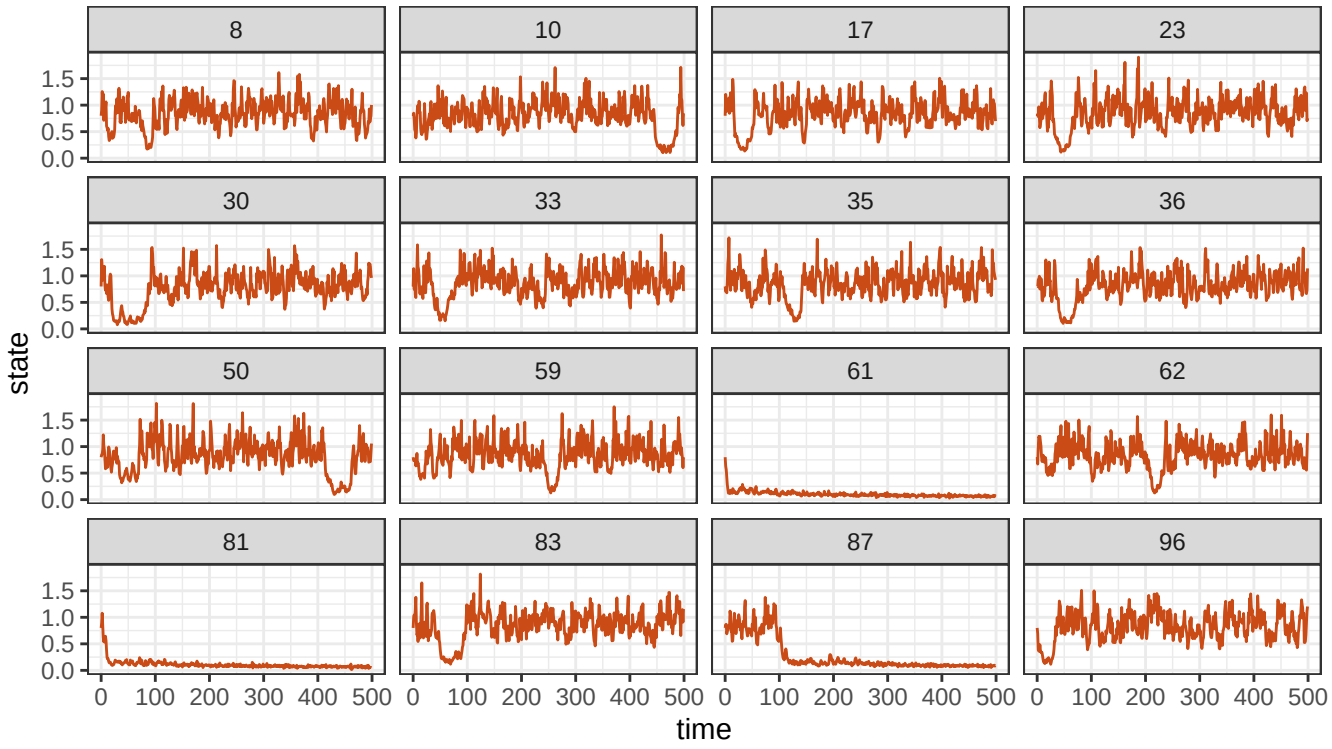
```
write_csv(sims_df, "figs/tipping_sims_df.csv")
write_csv(policy_df, "figs/tipping_policy_df.csv")
write_csv(reward_df, "figs/tipping_reward_df.csv")
```

```
# ensemble statistics
ymin <- function(x) last(x[(ntile(x, 20)==1)])
ymax <- function(x) last(x[(ntile(x, 20)==19)])

fig_sims <-
  sims_df %>%
   group_by(time, model) %>%
   summarise(ymin = ymin(state),
             ymax = ymax(state),
             state = mean(state), .groups = "drop") %>%
  ggplot(aes(time, state, ymin = ymin, ymax = ymax, fill=model)) +
   geom_ribbon(alpha= 0.3) + geom_line(aes(col = model))
```

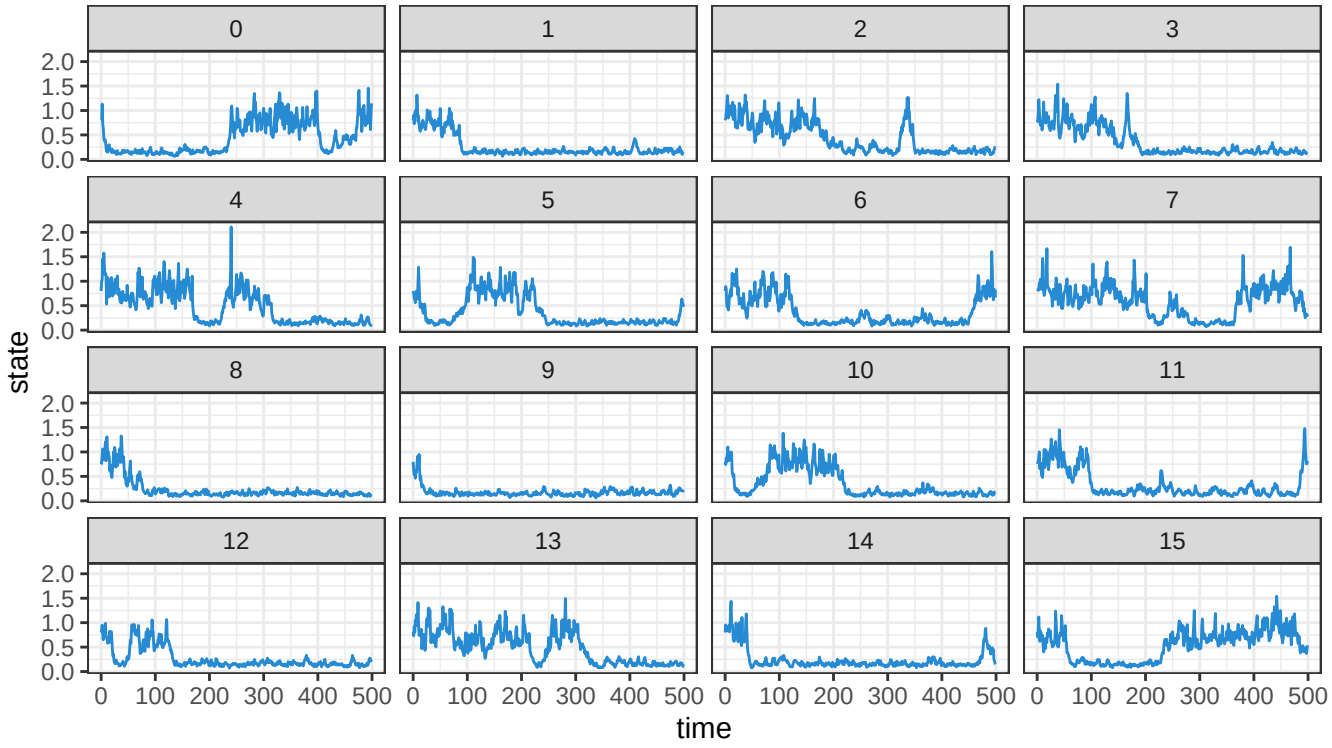
```
# Some individual replicates, for comparison
sims_df %>%
  filter(rep < 100, time < 500) %>%
  ggplot(aes(time, state, col=model, group=interaction(model, rep))) +
  geom_line(alpha = .1, show.legend = FALSE) + facet_wrap(~model)
```




```
# Some individual replicates, for comparison
is_low <- sims_df %>% filter(model == "TD3") %>% group_by(rep, model) %>% summarize(low = sum(state < .1
sims_df %>% inner_join(is_low) %>%
  ggplot(aes(time, state,  group=interaction(model, rep))) +
  geom_line(color = pal[3], show.legend = FALSE) + facet_wrap(~rep)
```




```
# Some individual replicates, for comparison
is_low <- sims_df %>% filter(model == "steady-state") %>% group_by(rep, model) %>% summarize(low = sum(s
sims_df %>% inner_join(is_low) %>%
  ggplot(aes(time, state, group=interaction(model, rep))) +
  geom_line(color = pal[1], show.legend = FALSE) + facet_wrap(~rep)
```



```
fig_policy <-
  policy_df %>% ggplot(aes(state, action,
                           group=interaction(rep, model),
                           col = model)) +
  geom_line(show.legend = FALSE)
```

```
fig_reward <- reward_df %>%
  ggplot(aes(time, mean_reward)) +
  geom_ribbon(aes(ymin = mean_reward - 2*sd,
                  ymax = mean_reward + 2*sd, fill = model),
              alpha=0.25, show.legend = FALSE) +
  geom_line(aes(col = model), show.legend = FALSE) +
  ylab("reward")
```

```
fig_sims / ( fig_policy + fig_reward)
```