Chapter 1

Development of a Ni-Catalyzed Enol Triflate-Halogen Exchange Reaction[1]

1.1 INTRODUCTION

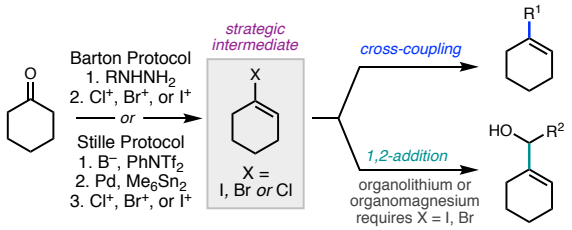
Alkenyl halides are versatile functional groups that can be used in a variety of carbon–carbon and carbon–heteroatom bond-forming reactions.[2,3] For example, alkenyl halides are commonly used as substrates in transition metal-catalyzed cross-coupling reactions or are converted via metal-halogen exchange to nucleophiles for 1,2-additions to carbonyl compounds (Figure 1.1).[4] Furthermore, the alkenyl halide moiety appears in some natural products and bioactive molecules.[5,6,7] Whereas acyclic alkenyl halides are easily prepared from the corresponding alkyne ,[9,10,11,12] or aldehyde,[13,14] most cyclic alkenyl halides are synthesized from the corresponding ketone. A commonly employed method is the Barton alkenyl halide synthesis (and variations thereof), which proceeds through an intermediate hydrazone.[15,16,17,18,19,20,21] These reactions are notoriously capricious: the formation of the requisite hydrazone can be challenging

[1] Portions of this report were reproduced from a published study (see reference 1) and the supporting information therein. The research presented in this chapter was completed in collaboration with Dr. Kelsey Poremba and Dr. Julie Hoftstra, former graduate students in the Reisman Group.

on sterically encumbered substrates and the halogenation step often produces mixtures of alkenyl halide isomers or dihalide side products.[14]

As a result, enol triflates, which can be prepared directly from cyclic ketones under either kinetic or thermodynamic control, have emerged as attractive "pseudohalides" for transition metal-catalyzed cross-coupling processes. Unfortunately, enol triflates cannot be directly converted to the corresponding alkenyllithium or alkenylmagnesium species commonly employed in 1,2-addition reactions. In cases where the Barton alkenyl halide synthesis is poor yielding, a multistep alternative is frequently employed: 1) conversion of the ketone to enol triflate, 2) conversion of the triflate to the stannane, and 3) conversion of the stannane to the halide.[22] Direct, mild methods to convert enol triflates to alkenyl halides, without proceeding through organostannane intermediates, can streamline the preparation of these valuable synthons (Figure 1.1).

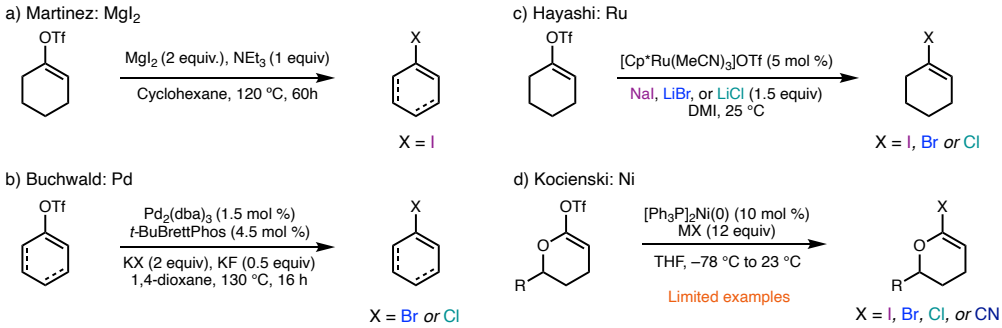
Figure 1.1 *Strategies to access alkenyl halides and their utility in organic synthesis.*



While Martinez and coworkers reported conversion of enol triflates to alkenyl iodides using anhydrous magnesium iodide and triethylamine, the reported scope is limited to four substrates and other alkenyl halides are not synthesized (Figure 1.2a).[23] As such, transition metal catalysis is most commonly used to carry out this transformation. Indeed, Buchwald has reported a Pd-catalyzed reaction to convert alkenyl triflates to alkenyl bromides and chlorides; however, there are no examples of alkenyl iodide formation, and the reaction requires an expensive ligand, temperatures greater than 100 °C, or additives such as fluoride salts or $^{i}Bu_3Al$ (Figure 1.2b).[24,25]

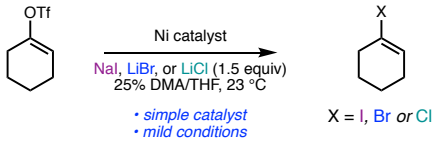
These additives limit the functional group compatibility of the transformation, particularly with commonly used groups such as silyl ethers. More recently, Hayashi reported a Ru-catalyzed method to convert enol triflates to iodides, bromides, or chlorides that proceeds at ambient temperature; however, the requisite ruthenium catalyst is not commercially available and limited examples of alkenyl iodide formation are reported (Figure 1.2c).[26,27]

Figure 1.2 *Transition metal catalyzed enol triflate-halogen exchange reactions.*



During prior investigations of Ni-catalyzed asymmetric reductive coupling reactions of alkenyl bromides and alkyl electrophiles,[28,29] an off-pathway halide exchange process was observed that generated alkenyl chlorides and iodides. Whereas Ni-catalyzed aryl and alkenyl halide exchange processes have been previously reported and extensively investigated,[30] development of the corresponding reactions of enol triflates have been limited to a single report describing bromination of dihydropyranyl enol triflates (Figure 1.2d).[31] As such, it was hypothesized that an appropriate Ni catalyst and inexpensive halide salts might enable the direct conversion of enol triflates to alkenyl halides under mild conditions. Herein, the development of a Ni-catalyzed triflate-halide exchange (triflex) reaction, which provides access to alkenyl iodides, bromides, and chlorides in good to excellent yields is reported.

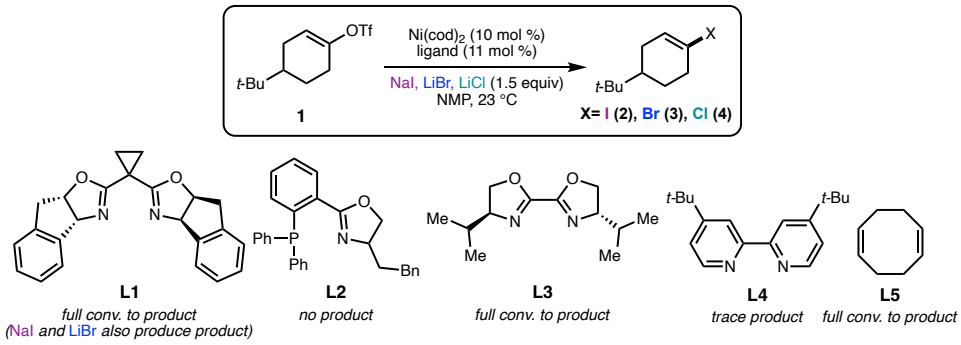
Figure 1.3 *Ni catalyzed halogenation of enol triflates.*



1.2 Reaction Discovery and Initial Optimization: Ni(cod$_2$)

Reaction development commenced with the chlorination of triflate **1**. Ni(cod)$_2$ (cod = cyclooctadiene) as a source of Ni^0, NMP as solvent, and LiCl as the source of chloride (Figure 1.4).[28,32,26,27] Where 4,4'-di-*tert*-butyl-2,2'-bypridine (dtbbpy), a commonly used ligand in Ni catalysis, and the phosphinooxazoline BnPhOX (**L2**) did not afford significant quantities of **2c**, bis(oxazoline) (BOX) **L1** and bi(oxazoline) (BiOX) **L3** both resulted in full conversion to the desired product. A follow-up control experiment omitting ligand revealed that ligands were not necessary for the transformation to proceed, as such further optimization efforts were performed in the absence of ligand.

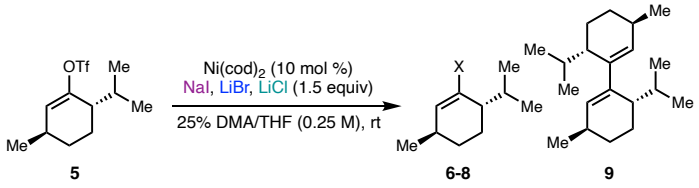
Figure 1.4 *Initial hit for enol triflate halogenation.*



After observing promising reactivity, optimization was carried out on enol triflate **5** (prepared in one step from menthone). Each reaction parameter was investigated: solvent, halide source, Ni loading, concentration, temperature, and ligand. While multiple solvents afforded high yields for the bromination and chlorination reactions, the iodination proved sensitive to solvent

effects, as DMA or mixed DMA/THF systems proved crucial to obtain high conversions. Due to improved physical properties of the mixed solvent system, 25% DMA/THF was deemed optimal. Although this data guided condition selection, alkenyl bromide **7** and alkenyl chloride **8** were ultimately found to be volatile leading to systematically low yields for these products.

Figure 1.5 *$Ni(cod)_2$ reaction optimization*



5 **6-8** **9**

			Iodination (**6**)		Bromination[1] (**7**)		Chlorination[1] (**8**)	
	Entry	Conditions	% Yield	% SM	% Yield	% SM	% Yield	% SM
Solvents	1	Control	74	3	74	0	74	0
	2	DMA	72	0	75	0	70	0
	3	THF	35	43	75	0	61	5
	4	DMF	34	47	74	0	70	3
	5	MeCN	4	85	52	36	7	81
Salts	6	NaX	74	3	58	6	10	69
	7	LiX	70	0	74	0	74	0
	8	KX	36	43	8	61	13	75
	9	TBAX	71	5	84	0	80	10
% Ni Loading	10	20 mol % Ni	70	0	55	0	67	0
	11	5 mol % Ni	68	4	83	0	77	0
	12	No Ni	0	82	0	96	0	94
Solvent Variations	13	10% DMA/THF	68	30	68	0	77	0
	14	40% DMA/THF	68	0	71	0	64	0
	15	0.1 M	67	0	71	0	63	0
	16	0.4 M	62	30	82	0	72	0
Temp	17	0 °C	12	74	61	26	61	32
	18	60 °C	77	10	80	0	72	0
Ligands	19	TMEDA	0	87	0	77	0	83
	20	dtbbpy	14	62	10	82	4	95
	21	dppf	0	91	0	74	0	61

[1] These products were found to be volatile

For all three reactions, none of the desired alkenyl halide products were observed in the absence of catalyst. Conversely, when higher Ni loading (20 mol %) was used, yields were hampered owing to increased amounts of alkene homodimerization. Whereas lower Ni loading (5 mol %) afforded high yields for the respective halogenations when **3** was used as a substrate, 10 mol % Ni was found to be more robust across a variety of substrates (Figure 1.4, entries 10-12).

Finally, concentration and temperature were evaluated. While increasing the temperature to 60 °C provided negligible improvement in yield, lowering the temperature to 0 ºC greatly suppressed conversion relative to the room temperature reaction. In contrast, concentration had a minimal effect on the reaction, with good yields obtained across 0.1 M to 0.4 M range (Figure 1.4, entries 15-18).

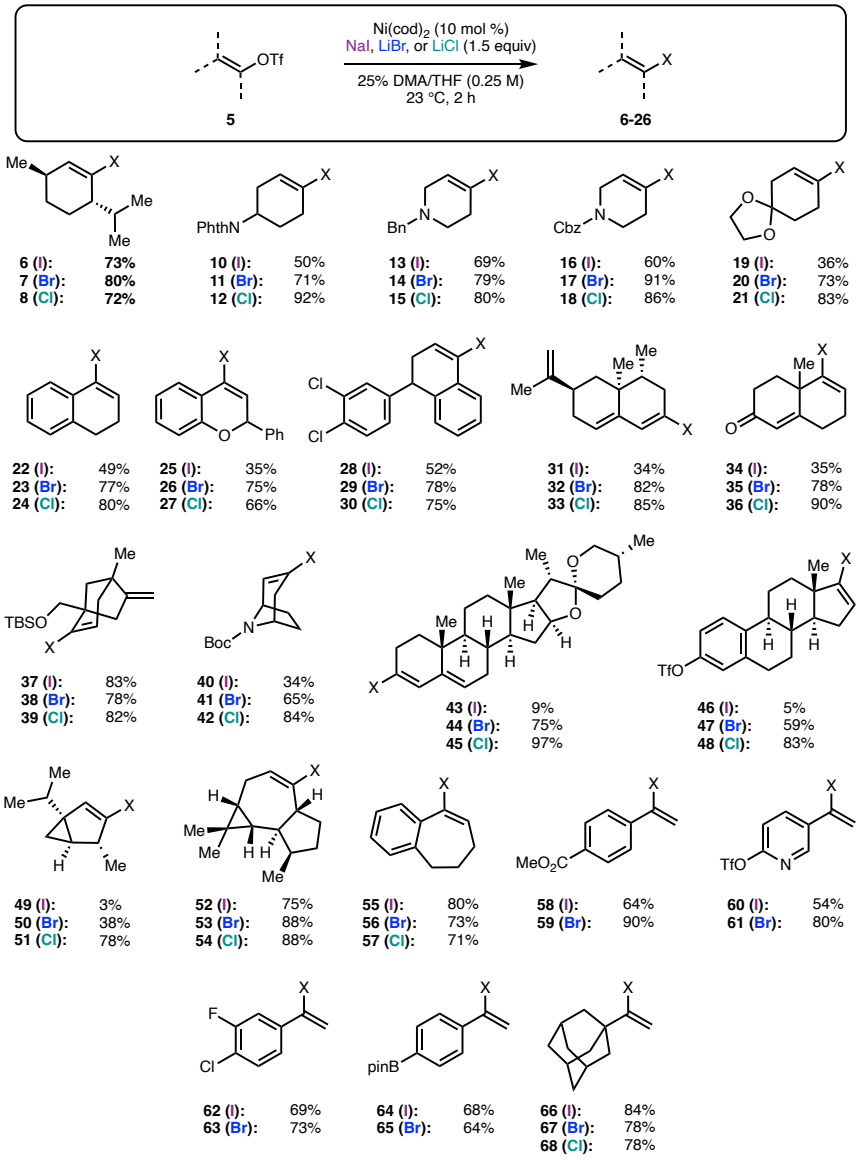
1.3 Substrate Scope: Ni(cod_2)

With generalizable conditions in hand, the substrate scope was investigated. The halogenations were found to be compatible with a variety of functional groups including tertiary amines (**13-15**), pyridines (**60** and **61**), carbamates (**16-18** and **40-42**), alkenes (**31-33** and **37-39)**, esters (**64** and **64**), ketals (**19-21** and **43-45**), and enones (**34-36**). Dienyl substrates (**31-33** and **43-45**) were well tolerated for the bromination and chlorination reactions, though the corresponding iodinations were lower yielding. Chemoselective halogenation of the alkenyl triflate was observed in the presence of aryl triflates (**46-48** and **60** and **61)**, chlorides (**28-30**, **62 a**nd **63**), fluorides (**62** and **63**), and boronates (**64** and **65**); however competitive halide exchange was observed in the presence of aryl bromides and iodides. Significantly, though $Ni(cod)_2$ is air and moisture sensitive, the iodination was scaled to 6 mmol as part of a benchtop protocol.

Though these reactions exhibit good functional group tolerance, each halogenation did not perform comparably well on all substrates. With the exception of 1-aryl-vinyl triflates (**58-65**), the chlorination afforded the most consistently high yields across various substrate classes. Under the general conditions, 1-arylvinyl triflates provided the corresponding bromides and iodides (**58-65**) in good yields; however, non-nickel mediated elimination to the aryl acetylenes outcompeted chlorination and the use of tetrabutylammonium salts did not improve the reaction.[33] In general, the iodination was most substrate dependent. For example, cyclopentenyl (**46-51**) and dienyl

triflates (**31-33** and **43-45**) afforded product in reduced yields, but good yields were generally afforded for cyclohexenyl and styrenyl systems.

Figure 1.6 *Substrate scope of enol triflate-halogen exchange: Ni(cod)$_2$*

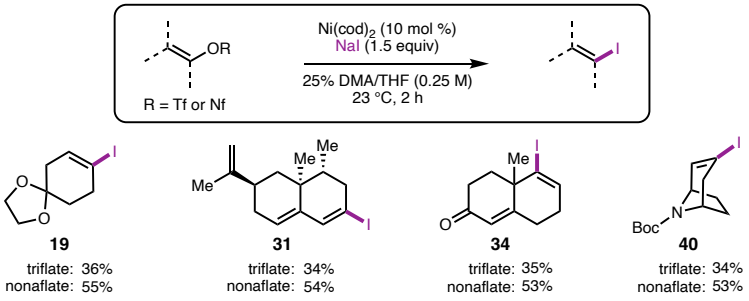


Reactions are conducted on 0.3 mmol scale under N_2. Isolated yields are provided (by NMR when yield <10%).

Although the reaction scope was relatively broad, some substrates performed poorly, particularly in the iodination reaction. In order to improve this reaction, modifications to the final reaction parameter, substrate, were pursued. Schöenebeck has reported improved yield for an enol-triflate-thiotrifluoromethyl exchange reaction by instead using the enol nonaflate.[34] As such, four

enol-nonaflates were prepared and subjected to the general reaction conditions and a 19% average yield increase was observed when the enol nonaflate substrate was employed (Figure 1.7). At present moment the driving force for this observation remains unclear, the more electron deficient nonaflate might increase the facility of oxidative addition or sulfonate-halide ligand exchange which affords improved reactivity.

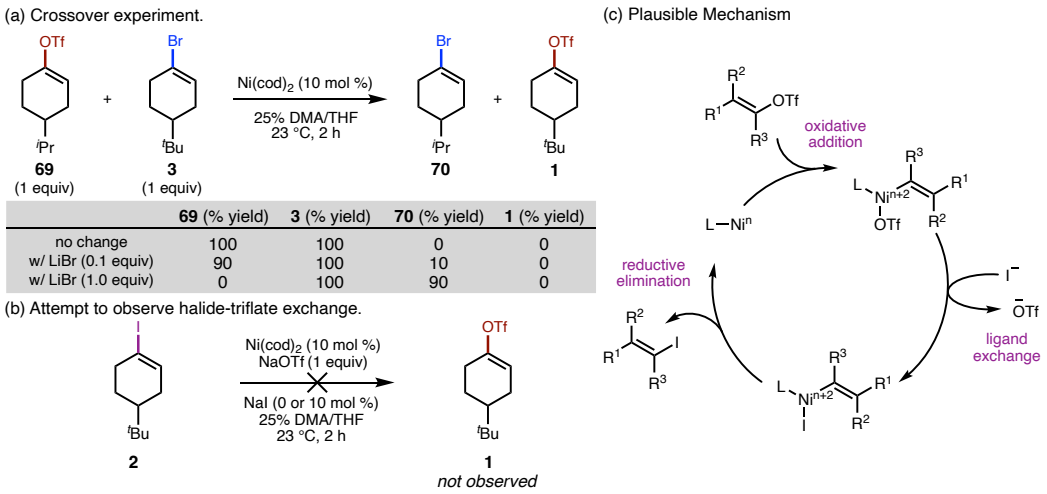
Figure 1.7 *Enol nonaflate iodination*



1.4 Mechanistic Experiments

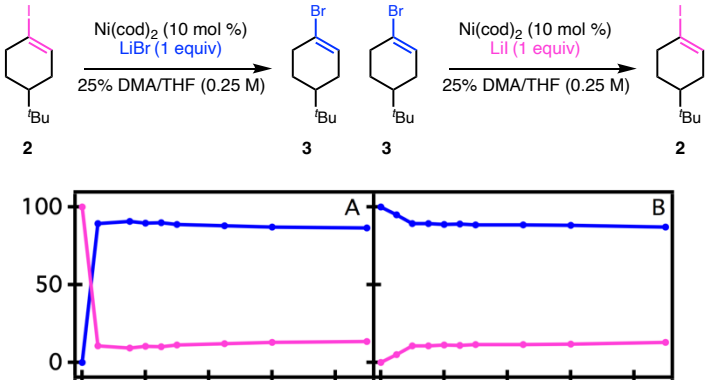
To assess if the reaction proceeds via thermodynatic or kinetic control a series of experiments were performed. Treatment of a 1:1 mixture of isopropyl triflate **69** and tert-butyl alkenyl bromide **3** with $Ni(cod)_2$ (10 mol %) in 1:3 DMA/THF at 23 °C resulted in complete recovery of triflate **69** and bromide **3**, without detection of crossover products **1** or **70** (Figure 1.8A). Addition of 0.1 or 1.0 equiv LiBr resulted in conversion of isopropyl triflate **69** to the corresponding bromide **70** in 10% and 90% yield, respectively; no tert-butyl triflate **1** was detected at any point in either reaction. Similarly, subjection of alkenyl iodide **2** to $Ni(cod)_2$ (10 mol %) and metal triflate salts (e.g. NaOTf) did not result in enol triflate formation (Figure 1.8B). Because equilibrium control *necessitates viability of the reverse reaction*, which is not observed, it was concluded that the reaction proceeds under *irreversible kinetic control*.

Figure 1.8 *Attempted halide-triflate crossover and halide-triflate exchange*



The irreversibility of the overall transformation necessitates that one or more elementary steps in the catalytic cycle be irreversible. A simple catalytic cycle for this transformation might consist of three elementary steps: oxidative addition, ligand exchange, and reductive elimination (Figure 1.8C). Given that analogous alkenyl halide exchange reactions display reversible behavior (*vide infra*), it follows that C-X reductive elimination is reversible. As such, either oxidative addition into the enol triflate or triflate-halide ligand must be irreversible. In either scenario, irreversible consumption of the enol triflate enables the reaction to proceed in good yield to the respective alkenyl halides.

Figure 1.9 *Halide exchange*

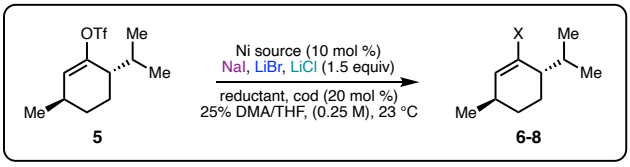


In order to compare the triflex reaction with canonical halide exchange reactions, the reversibility of alkenyl halide formation was investigated.[30] Treatment of alkenyl iodide **2** with 1 equiv. lithium bromide under standard conditions afforded an 85:15 mixture of bromide **3** to iodide **2**. In a similar vein, the treatment of alkenyl bromide (**1-Br**) with 1 equiv LiI afforded the same 85:15 mixture after 2h. As a result, it can be concluded that this reaction, unlike the triflex reaction, proceeds via a thermodynamic equilibrium (Figure 1.9).

1.5 Evaluation of Ni(II) Pre-catalysts

In an effort to improve the accessibility of this method, Ni(II) precatalysts were investigated. Optimization commenced with enol triflate **5**, NiX_2 salts and Mn or Zn reductant in the presence or absence of cod (Figure 1.10). Though the *in situ* reduction protocol gave no detectable amounts of chlorination product **8**, it was hypothesized these results were complicated by the poor solubility of $NiCl_2$ in the mixed solvent system. As such, more soluble NiX_2(dme) precatalysts were evaluated. Gratifyingly, the use of $Ni(Cl_2)$dme dramatically increased the yield of the chlorination reaction to 87% while maintaining comparably high reactivity for the bromination reaction (Figure 1.10, Entry 4). Unfortunately, NiI_2(dme) is not commercially available, which precluded its use in this study.

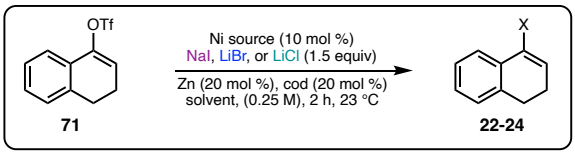
Figure 1.10 *$Ni(X)_2$ preliminary optimization*



			I (**6**)	Br (**7**)	Cl (**8**)
Entry	Ni Source	reductant	Yield (%)	Yield (%)	Yield (%)
1	NiX_2	10 mol % Zn	28	84	0
2	NiX_2	20 mol % Zn	25	85	0
3	NiX_2	100 mol % Zn	14	24	0
4	NiX_2(dme)	20 mol % Zn	—	87	87

In order to circumvent the reactivity differences brought about by switching from halide to halide using NiX_2 pre-catalysts, alternative pre-catalysts were evaluated with the aim of identifying a unified pre-catalyst (Figure 1.11). For this study, enol triflate **7**, derived from α–tetralone, was used. A screen of Ni sources in DMA and 25% DMA/THF showed that $Ni(OAc)_2{\cdot}4H_2O$ was unique in its ability to catalyze all three reactions (Figure 1.11 entry 5). Although $Ni(acac)_2$ performed well for the bromination reaction, the iodination reaction afforded no catalyst turnover, while $Ni(OTf)_2$ failed to catalyze either reaction (Figure 1.11 entry 3).

Figure 1.11 *Evaluation of other Ni(II) salts*

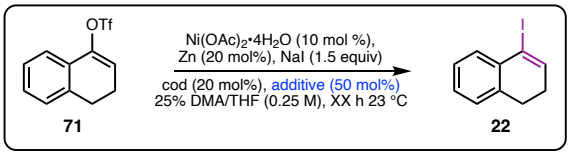


			I (**22**)	Br (**23**)	Cl (**24**)
Entry	Solvent	Ni Source	Yield (%)	Yield (%)	Yield (%)
1	DMA	$Ni(acac)_2$	4	97	–
2	25% DMA/THF	$Ni(acac)_2$	4	91	–
3	DMA	$Ni(OTf)_2$	5	0	–
4	DMA	$Ni(OAc)_2{\cdot}4H_2O$	0	39	–
5	25% DMA/THF	$Ni(OAc)_2{\cdot}4H_2O$	33	95	99

Given the bromination and chlorination reactions were high yielding, optimization moved forward on the iodination using $Ni(OAc)_2{\cdot}4H_2O$ as pre-catalyst. Though preliminary kinetics experiments using $Ni(cod)_2$ displayed confounding behavior (data not presented), the reaction appeared to be positive order in Ni, deviating from linearity at higher concentrations. One plausible explanation could be concentration dependent oligomerization of monomeric Ni species, which are catalytically inactive.[35] As such, it was hypothesized that off pathway Ni oligomers were forming in our reaction, which might be destabilized by addition of an appropriate nucleophile (Figure 1.12). It was found that DMAP (Figure 1.12, Entry 3) afforded the desired alkenyl iodide in 57% yield after just 2 hours. Hypothesizing that the iodination might be slower than the

bromination and chlorination reactions, reaction time was extended and complete conversions could be obtained to afford the desired product **22** in 95% yield in 16h with 20 mol % DMAP (Figure 1.12, Entry 6).

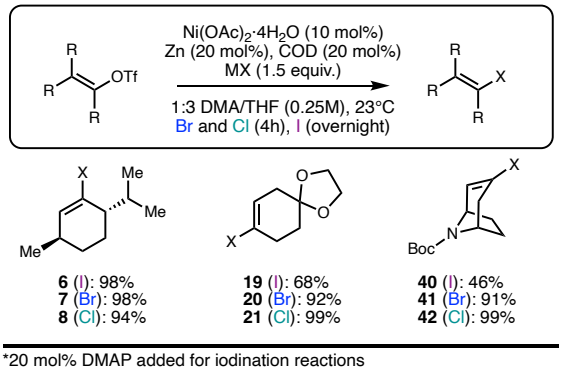
Figure 1.12 *Additive and Reaction Time Screen*



Entry	Additive	Time (h)	Yield (%)
1	DABCO (0.5)	2	0
2	Quinuclidine (0.5)	2	0
3	DMAP (0.5)	2	57
4	DMAP (0.4)	5	83
5	DMAP (0.4)	16	93
6	DMAP (0.2)	16	95

Whereas high yielding conditions had been developed for all three halogenations using **71** as substrate, a preliminary substrate screen revealed that the iodination was less robust across lower yielding substrates (Figure 1.13 **19** and **40**).

Figure 1.13 *Ni(II) preliminary scope screen*



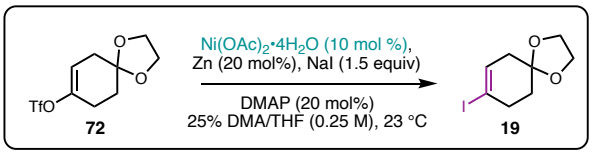
*20 mol% DMAP added for iodination reactions

At this stage, a control experiment revealed that reactions without cod provided comparable yield of alkenyl iodide **19**; thus cod was omitted during further screening (Figure 1.14A entries 1 and 4). A screen of Ni loadings suggested that 5 mol % performed best for this substrate. In an attempt to further optimize the reaction, enol triflates **72** and **73** were selected for additional

studies. In particular, catalyst loading, sodium iodide loading and electronics of the pyridine additive were evaluated. Indeed a screen of electron rich pyridines (albeit with 1.1 equiv. NaI) suggested that the strongly electron donating dimethyl amino moiety (σ = -0.83) was important for obtaining reasonable levels of conversion; for example, use of the corresponding 4-methoxy (σ = -0.27) and 4-methyl (σ = -0.17) pyridines gave the product **19** in 8% and 1% respectively, under otherwise identical conditions (Figure 1.14B). With respect to NaI concentration, lowering loading to 1.1 equiv. dropped the yield to 49% (Figure 1.14C Entry 1), while increasing the loading to 3.0 equivalents improved the yield to 85% (Figure 1.14C Entry 3).

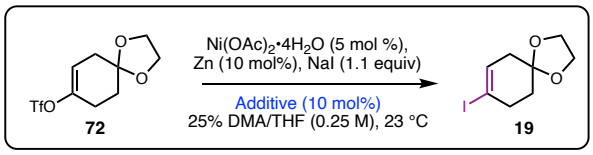
Figure 1.14 *Optimization of Ni/NaI loadings and pyridine electronics: ketal substrate*

A) Ni Loading



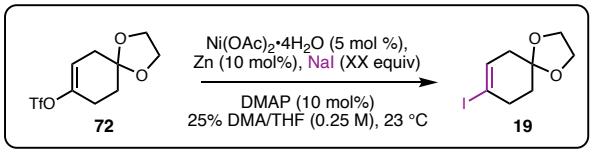
Entry	Deviation	Yield (%)
1	+ cod (20 mol%)	68
2	2.5 mol % Ni, 5 mol% Zn	62
3	5 mol % Ni, 10 mol% Zn	75
4	none	70
5	20 mol % Ni, 40 mol% Zn	65

B) Pyridine Electronics



Entry	Additive	Yield (%)
1	DMAP	49
2	4-MeOPy	8
3	4-MePy	1

C) NaI Loading

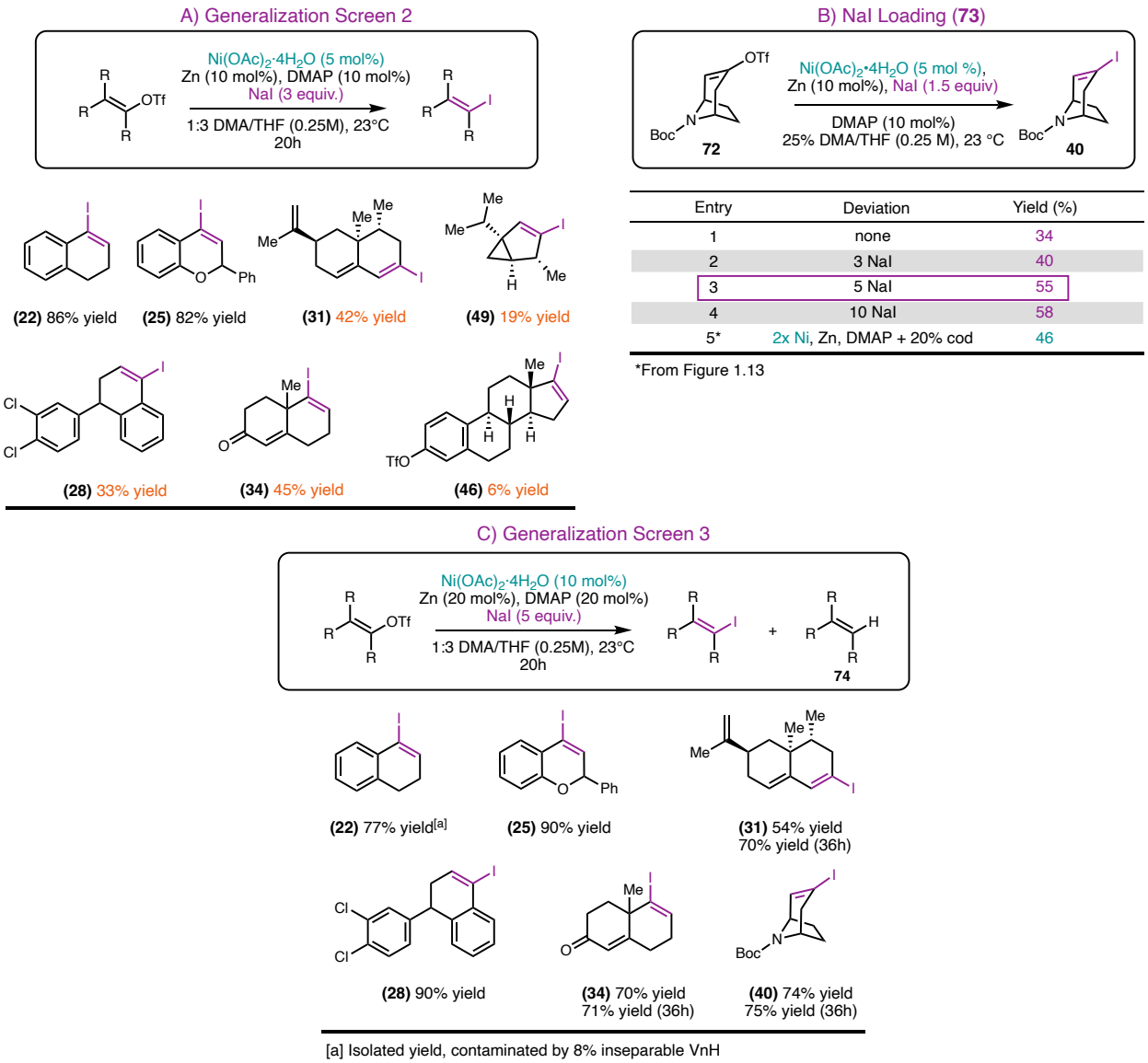


Entry	Equiv. NaI	Yield (%)
1	1.1	49
2	1.5	75
3	3	85
4	5	81
5	10	82

Although these conditions (Figure 1.14C, Entry 3) worked well for substrate **72**, we were disappointed to find that they afforded yields below 50% for five of seven additional substrates that were evaluated (Figure 1.15A). Given that NaI stoichiometry had a pronounced effect on the

reaction yield when substrate **72** was used, we opted rescreen this variable on another challenging substrate, **73** and found that 5 equiv. NaI was optimal in this case (Figure 1.15B, entry 3). Instead of completely reevaluating every variable under these conditions, past results were examined for substrate **73** in order identify which other variables might provide the greatest impact on yield. It was noted that 10 mol % Ni and 1.5 equiv NaI (Figure 1.15B, entry 5) afforded 46% yield compared to 34% using 5 mol% Ni and 1.5 equiv. NaI (Figure 1.15B, entry 1). As such, a third

Figure 1.15 *Toward General Iodination Conditions*



generalization screen was run in which the catalyst and NaI loadings were increased to 10 mol% and 5.0 equivs respectively. These conditions afforded greater than 70% yield for all but one product (**31**) and when reaction time was increased to 36h 70% yield was afforded for this product (**31**) as well (Figure 1.15C).

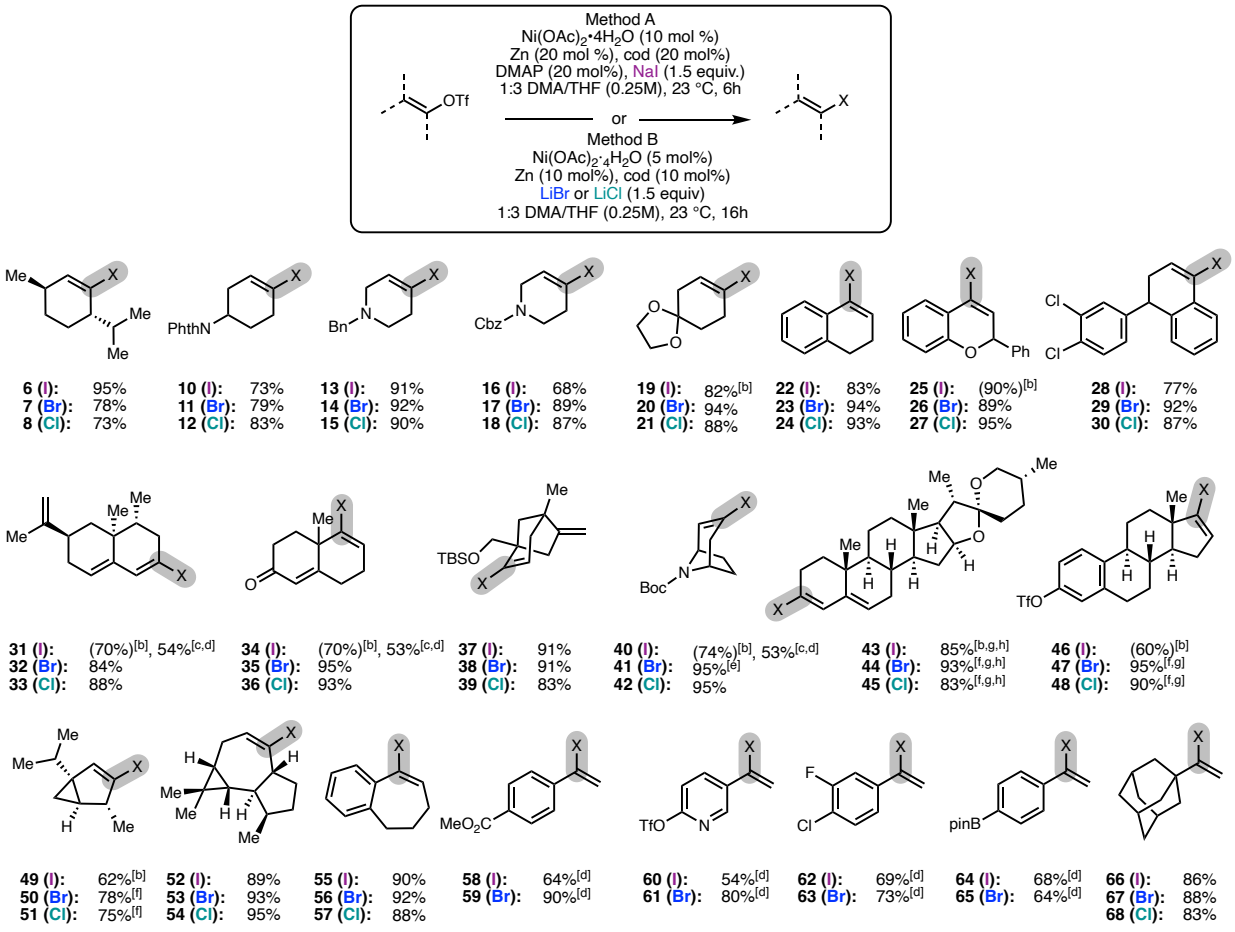
Although these conditions worked well on screening scale (0.1 mmol), upon scale-up, increased levels (8%) of inseparable reduction side product **74** were observed. Analysis of the screening data suggested that the amount of reduction depended on three factors: reaction time, Ni loading, and substrate. Ultimately, the amount of reduction increased with prolonged reaction time and higher Ni loadings, with up to equimolar amounts of Ni and reduction observed. Given that several substrates required longer reaction times and higher Ni loadings in order to obtain satisfactory conversions, we elected to use different iodination conditions, depending on the substrate employed. For reactive substrates (**6, 10, 13, 16, 22, 28, 37, 52,** and **55**), the use of 1.5 equivalents NaI and 20 mol % cod were used, with reaction times of 6h. For unreactive substrates (**19, 25, 31, 34, 40, 43, 46,** and **49**), reactions were carried out with 5 equivalents NaI (in the absence of cod) for 36 hours (Figure 1.16).

1.6 Final Substrate Scope

With satisfactory conditions in hand, the substrate scope of the Ni-catalyzed halogenation was investigated (Figure 1.16). Similar to the conditions developed with $Ni(cod)_2$, the halide exchange was compatible with a variety of common functional groups, including amines (**13-15**), carbamates (**16-18** and **40-42**), alkenes (**31-33** and **43-45**), dienes (**31-33** and **43-45**), ketals (**19-21** and **43-45**), and enones (**34-36**). Moreover, chemoselective halogenation of enol triflates was observed in preference to aryl triflates (**46-48**) and aryl chlorides (**28-30**).

The bromination and chlorination reactions were generally more efficient and robust. For most substrates, complete conversions were achieved with 5 mol% Ni and without the need for DMAP, although substitution of DMAP for cod improved the yields for substrates where incomplete conversion was observed (**43-51**). In addition, for 1-arylvinyl triflates (**22-25**, Figure 1.16) the use of $Ni(cod)_2$ (Method C) provided cleaner reaction profiles for the bromination and iodination reactions. To demonstrate the scalability of the reaction, bromide **41** was prepared in 95% yield on 1 mmol scale using a benchtop setup.

Figure 1.16 *Final Substrate Scope for Triflex*



[a] Reactions conducted under inert atmosphere on 0.3 mmol scale. Isolated yields. Yields in parentheses were determined by ^1H NMR spectroscopy versus 1,2,4,5-tetrachloronitrobenzene as an internal standard. [b] 5 equiv NaI was used in the absence of cod, 36 h reaction time. [c] Enol nonaflate was employed instead of enol triflate. [d] Method C: $Ni(cod)_2$ (10 mol %), MX (1.5 equiv), 25% DMA/THF (0.25M), 23 C, 16 h. [e] 1 mmol scale, benchtop protocol. [f] DMAP (10 mol %) was used instead of cod. [g] Reaction was conducted on 0.2 mmol scale. [h] Reaction was conducted at 0.125 M due to poor solubility of enol triflate.

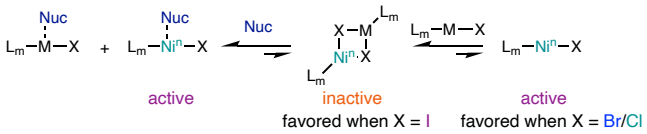
1.7 Role of DMAP

The improvement of the iodination reaction in the presence of DMAP warrants further discussion. During the development of a thiotrifluoromethylation of aryl chlorides, Schöenebeck and coworkers reported the remarkable effect of MeCN as an additive on the reaction.[36] Though the initially developed system ($Ni(cod)_2$/dppf, PhMe) afforded catalysis across a variety of substrates, the yield of the transformation was highly variable (40-98%). In order to expand the scope, the authors found the addition of 1 equiv. MeCN greatly improved the overall reactivity, indeed, substantial increases in yield (ca. 20 to 50+ %) were noted for several substrates. Computational studies suggest MeCN serves to displace cod and destabilize the Ni(dppf) complex responsible for oxidative addition; thereby decreasing the overall barrier to oxidative addition, which accelerates product formation.

A retrospective evaluation of the reaction(s) illuminates a bifurcated behavior wherein the bromination and chlorination reactions are generally high yielding and robust while the iodination reaction is sluggish and low yielding in the absence of DMAP. Given that equilibrium control has been ruled out (*vide supra*), these observations cannot simply be explained by bond strength arguments alone as such kinetic arguments must be considered. Several studies have determined that complexation of PdX_2 with phosphine ligands affords exclusively monomeric species when X = Cl or Br, but favors the dimeric species when X = I. Moreover, Buchwald and coworkers have shown that the rate cleavage of L_nPdX_2 dimers with dibenzylamine follows the trend of Cl ≈ Br > I. As such, it is proposed that the sluggish iodination reactivity may be attributed to formation of inactive multi-metallic complexes in the absence of additives (Figure 1.17). Thus, one possible role of DMAP in the triflex reaction could be to destabilize inactive bimetallic (Ni-X-Ni and Ni-

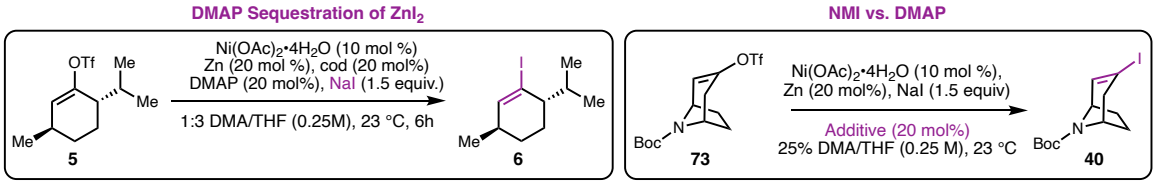
X-Zn) complexes, pushing the equilibrium to reactive monomeric species, and thereby improving reactivity.

Figure 1.17 *Proposed effects of Zn(II) and DMAP on Triflex*



In order to test this hypothesis, a set of addition experiments were carried out. Addition of 1 equiv. ZnI_2 to the iodination of enol triflate **5** afforded a precipitous drop in reactivity to 29% yield accompanied by recovered starting material. In order to counteract this effect, 1 equiv. DMAP was added in concert with 1 equiv. ZnI_2, which restored reactivity back to 91% yield. These results are consistent with the above hypothesis; increasing [ZnI_2] should favor formation of Ni-X-Zn complexes via Le Chatelier's Principle, while DMAP should counteract this effect by sequestration of Zn(II) (Figure 1.18).

Figure 1.18 *Role of DMAP and NMI*



Entry	Deviation	%VnI
1	None	92
2	1 equiv. ZnI_2	29
3	1 equiv ZnI_2 + 1 DMAP	91

Entry	Additive	Yield (%)
1	DMAP	74
2	NMI	68

Further support for Zn(II) non-innocence can be found in the literature. Diao and coworkers reported preparation of a multimetallic Ni-X-Zn complex XantphosNi(Br)·$ZnBr_2$ in high yield by reduction of the Ni(II) precursor with Zn^0.[37] In addition, McNally and coworkers recently reported the addition of 0.5 equiv. NMI improved the yield of Co-catalyzed Negishi-type couplings of heteroarylphosphonium salts and alkyl Zn reagents.[38] Similar to the above discussion, the authors

hypothesize that NMI sequesters the Zn(II) byproduct, which is otherwise deleterious. Analysis of the supporting information revealed that replacement of NMI with DMAP provided a similar reaction outcome. In order to see if this effect could be recapitulated in the triflex system, NMI was swapped for DMAP using the optimized conditions for sluggish iodination substrates. Gratifyingly, this modification provided 68% yield of the desired product along with a similar reaction profile as observed with DMAP, providing a final piece of support for the above hypothesis (Figure 1.18).

1.8 Conclusion

In conclusion, two protocols for Ni-catalyzed halogenation of enol triflates have been developed. By modifying the halide salt, alkenyl iodides, bromides, or chlorides can be obtained using simple, commercially available catalyst systems. Using $Ni(OAc)_2 \cdot 4H_2O$ in conjunction with cod and/or DMAP as additives, high yields of the desired alkenyl halides can be obtained; although under these conditions, the inseparable reduction product can be observed in varying quantities. In contrast, using $Ni(cod)_2$ in the absence of exogenous ligands or additives, highly pure alkenyl halides can be isolated; although these reactions generally afford lower yields. In either case, the reactions proceed at room temperature and exhibit good functional group tolerance. Preliminary mechanistic investigations suggests that the reaction proceeds via kinetic control and is inhibited by ZnX_2 salts which may be sequestered by exogenous halide or DMAP. This contrasts with canonical halogen exchange reactions, which are governed by thermodynamic equilibria.

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1.10 Supporting Information

1. Materials and Methods

Unless otherwise stated, reactions were performed under a N_2 atmosphere using freshly dried solvents. Tetrahydrofuran (THF) and methylene chloride (CH_2Cl_2) were dried by passing through activated alumina columns. Diisopropylamine (*i*-Pr_2NH) was distilled over calcium hydride prior

to use. Anhydrous dimethylacetamide (DMA), sodium iodide (NaI), lithium bromide (LiBr), and lithium chloride (LiCl) were purchased from Aldrich and stored under N_2. $Ni(cod)_2$ was purchased from Strem and stored in the glovebox at –20 °C. Unless otherwise stated, chemicals and reagents were used as received. All reactions were monitored by thin-layer chromatography using EMD/Merck silica gel 60 F254 pre-coated plates (0.25 mm) and were visualized by UV, CAM, or $KMnO_4$ staining. Flash column chromatography was performed as described by Still et al.[39] using silica gel (230-400 mesh, Silicycle). Purified compounds were dried on a high vacuum line (0.2 torr) to remove trace solvent. Optical rotations were measured on a Jasco P-2000 polarimeter using a 100 mm path-length cell at 589 nm. ^1H and ^{13}C NMR spectra were recorded on a Bruker Avance III HD with Prodigy cyroprobe (at 400 MHz and 101 MHz, respectively), a Varian 400 MR (at 400 MHz and 101 MHz, respectively), or a Varian Inova 500 (at 500 MHz and 126 MHz, respectively). ^1H and ^{19}F NMR spectra were also recorded on a Varian Inova 300 (at 300 MHz and 282 MHz, respectively). NMR data is reported relative to internal $CHCl_3$ (^1H, δ = 7.26), $CDCl_3$ (^{13}C, δ = 77.0), CD_3CN (^1H, δ = 1.94), CD_3CN (^{13}C, δ = 1.32), and C_6F_6 (^{19}F, δ = -161.64). Data for ^1H NMR spectra are reported as follows: chemical shift (δ ppm) (multiplicity, coupling constant (Hz), integration). Multiplicity and qualifier abbreviations are as follows: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. IR spectra were recorded on a Perkin Elmer Paragon 1000 spectrometer and are reported in frequency of absorption (cm^{-1}). HRMS were acquired from the Caltech Mass Spectral Facility using fast-atom bombardment (FAB), electrospray ionization (ESI-TOF), or electron impact (EI).

2. Optimization of Reaction Parameters

a. General Procedure 1: (Table 1 and Table S1) A 1-dram vial equipped with a stir bar was brought into an N_2- filled glovebox. The vial was charged with $Ni(OAc)_2 \cdot 4H_2O$ (0.05 or 0.01 equiv); Zn (0.1 or 0.2 equiv); LiCl, LiBr, or NaI (1.5 equiv); and COD (0.1 or 0.2 equiv). Anhydrous DMA and THF were added in a 1:3 ratio (0.25M overall), resulting in a blue (bromination and chlorination) or yellow/green (iodination) color. Enol triflate (was added neat, the vial was sealed with a Teflon cap, and brought out of the glovebox to stir on the bench (600 rpm) for 6 (iodination) or 16 (bromination and chlorination) hours at room temperature. The reaction was quenched by eluting through a small plug of silica gel (5 cm of silica in a large glass

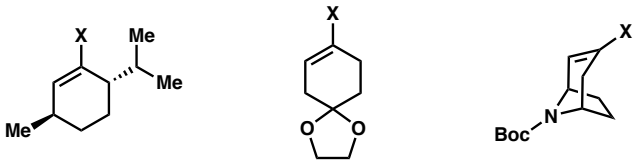
pipette) with 40% Et_2O/pentane (10 mL collected). The crude reaction mixture was concentrated under reduced pressure and analyzed by NMR with tetrachloronitrobenzene as an external standard.

b. General Procedure 2: (Table S2) A 1-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with NaI, LiBr, or LiCl (0.15 mmol, 1.5 equiv) and $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 0.1 equiv). Anhydrous DMA (0.1 mL) and THF (0.3 mL) were added, resulting in a clear yellow solution. Enol triflate (0.1 mmol, 1.0 equiv) was added neat, turning the reaction dark red (NaI) or aqua blue (LiBr or LiCl) over several minutes. The vial was sealed with a Teflon cap and brought out of the glovebox to stir on the bench (480 rpm) for two hours at room temperature. The reaction was quenched by eluting through a small plug of silica gel (5 cm of silica in a large glass pipette) with 40% Et_2O/pentane (10 mL collected). The crude reaction mixture was concentrated under reduced pressure and analyzed by NMR with tetrachloronitrobenzene as an external standard.

c. Investigating Ni(II) Reduction

<u>$Ni(acac)_2$ reduction with DIBAL</u>

Nine 1-dram vials equipped with a stir bar were brought into a N_2-filled glovebox. The vials were charged with $Ni(acac)_2$ (2.6 mg, 0.01 mmol), PPh_3 (5.3 mg, 0.2 mmol), and THF (1 mL) and sealed with a Teflon cap containing a rubber septum. The vials were brought out of the glovebox at which point diisobutylaluminum hydride (3.6 μl, 0.02 mmol) was added and the reactions were stirred on the benchtop (dark red/brown color noted on addition of DiBAl). After 15 min the reactions were cooled to –78 °C and freshly prepared solution of LiX in THF (1 mL, 1.2 mmol) was added followed by enol triflate (0.1 mmol in 0.5 ml THF, 1 equiv.). The reactions were gradually warmed to room temperature overnight at which point they were quenched by addition of saturated aq. $NaHCO_3$ (5 mL) and extracted with EtOAc (3 x 5 ml). The combined organic phase was washed with brine (15 ml), dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and analyzed by NMR with an internal standard (1,2,4,5-tetrachloronitrobenzene).



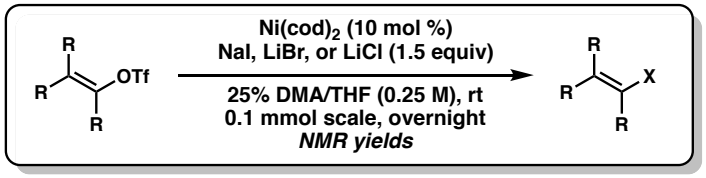
Cl: 3% yield
Br: 5% yield
I: 0% yield

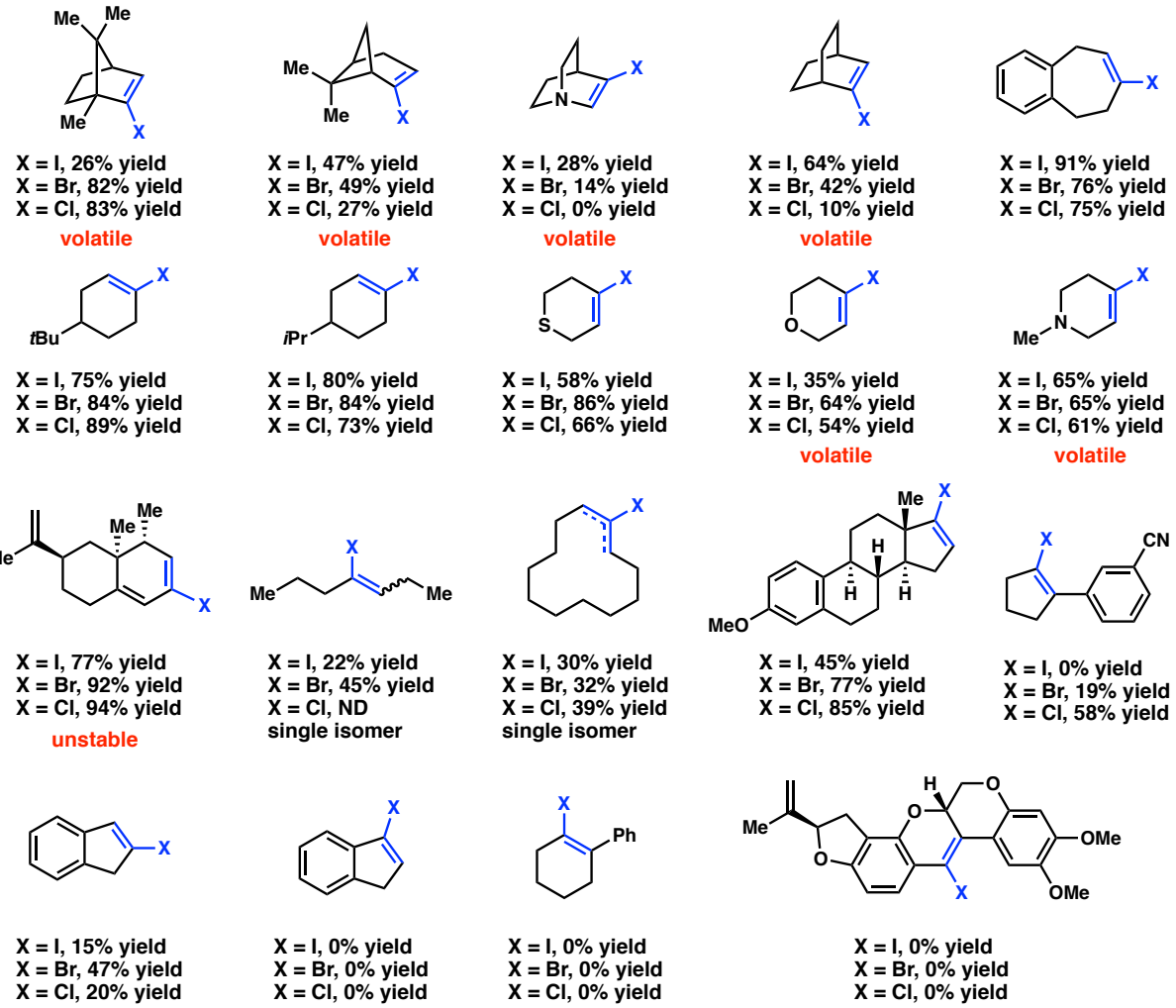
Cl: 0% yield
Br: 12% yield
I: 17% yield

Cl: 0% yield
Br: 8% yield
I: 7% yield

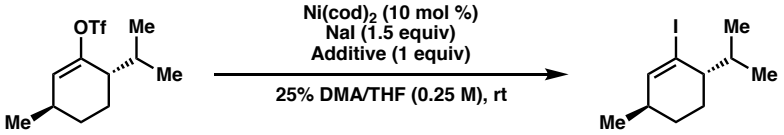
d. NMR Yields for Additional Substrate Halogenations

Table S1: Additional Enol Triflate Halogenations





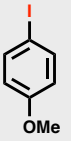
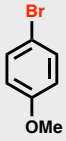
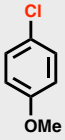
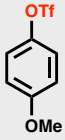
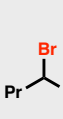
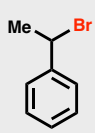
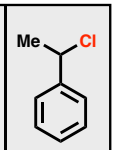
e. Robustness Screen



A 1-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with NaI (22 mg, 0.15 mmol, 1.5 equiv) and $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 0.1 equiv). Anhydrous DMA (0.1 mL) and THF (0.3 mL) were added, resulting in a clear yellow solution. Additive (0.1 mmol, 1 equiv) and enol triflate (28 mg, 0.1 mmol, 1 equiv) were added neat. The vial was sealed with a Teflon cap and brought out of the glovebox to stir on the bench (480 rpm) for two hours at room temperature. Reaction was quenched by eluting through a small plug of silica gel (5 cm of silica in a large glass pipette) with 40% Et_2O/pentane (10 mL collected). The crude reaction mixture was concentrated under reduced pressure and analyzed by NMR with an added standard

(tetrachloronitrobenzene). **The reaction with the addition of 4-iodoanisole was charged with LiBr (1.5 equiv), not NaI.*

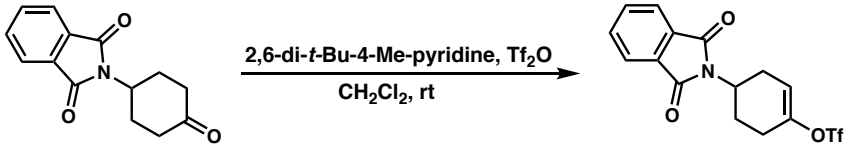
Table S2: Tolerance of other Cross-Coupling Handles

Additive	none								
Recovery of Additive	–	19%	37%	65%	100%	100%	47%	32%	87%
Yield of Alkenyl Iodide	77%	31%	37%	72%	29%	73%	31%	0%	59%
Other Products from Additive	–	71% ArBr	25% ArI	–	–	–	13% alkyl I	76% BnI	–

3. Substrate Preparation

a. Enol Triflates

4-(1,3-dioxoisoindolin-2-yl)cyclohex-1-en-1-yl trifluoromethanesulfonate (75)



To a round bottom flask was added 2-(4-oxocyclohexyl)isoindoline-1,3-dione (730 mg, 3.0 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (924 mg, 4.5 mmol, 1.5 equiv), CH_2Cl_2 (10 mL), and trifluoromethanesulfonic anhydride (757 µL, 4.5 mmol, 1.5 equiv) sequentially. The reaction was stirred at room temperature overnight, then diluted with hexanes and filtered over a plug of Celite. The Celite was washed with CH_2Cl_2. The organic filtrate was washed with H_2O and brine, and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 30% EtOAc/hexanes) to yield 752 mg (67% yield) of a white solid.

R_f = 0.30 (silica, 30% Et_2O/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (dd, *J* = 5.5, 3.0 Hz, 2H), 7.77 – 7.66 (m, 2H), 5.78 (dt, *J* = 5.9, 2.3 Hz, 1H), 4.43 (dddd, *J* = 12.7, 10.8, 5.5, 3.1 Hz, 1H), 3.07 (dddt, *J* = 17.3, 10.7, 4.3, 2.3

Hz, 1H), 2.81 – 2.68 (m, 1H), 2.68 – 2.54 (m, 1H), 2.52 – 2.40 (m, 1H), 2.39 – 2.26 (m, 1H), 1.92 (dddd, J = 12.5, 5.9, 3.8, 1.8 Hz, 1H).

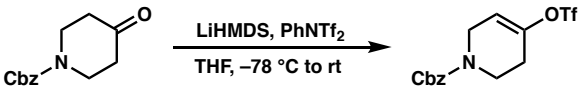
^{13}C NMR (101 MHz, $CDCl_3$): δ 168.2, 148.2, 134.3, 131.9, 123.4, 118.6 (q, J_{C-F} = 320.2 Hz), 116.9, 45.6, 27.7, 26.7, 26.1.

^{19}F NMR (282 MHz, $CDCl_3$): δ -73.7.

FTIR (NaCl, thin film, cm^{-1}): 1704, 1698, 1418, 1385, 1249, 1196, 1139, 1112, 876, 718.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{15}H_{13}F_3O_5NS$ $[M+H]^+$: 376.0467; found: 376.0467.

Benzyl 4-(((trifluoromethyl)sulfonyl)oxy)-3,6-dihydropyridine-1(2*H*)-carboxylate (76)



Benzyl 4-oxopiperidine-1-carboxylate (1.17 g, 5.0 mmol, 1.0 equiv) was added to a round-bottom flask and placed under an atmosphere of N_2. THF (25 mL) was added and the reaction was cooled to –78 °C. LiHMDS (5.5 mL, 1 M in THF, 5.5 mmol, 1.1 equiv) was added dropwise and allowed to stir for 30 minutes before N-phenyl-bis(trifluoromethanesulfonimide) (1.88 g, 5.25 mmol, 1.05 equiv) was added in one portion. The reaction was allowed to reach room temperature and stir overnight. The reaction was then quenched with saturated aq. NH_4Cl (50 mL) and extracted with Et_2O (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 20% Et_2O/hexanes) to yield 901 mg (49% yield) of a colorless oil.

R_f = 0.30 (silica, 30% Et_2O/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, d_3-MeCN, 65 °C): δ 7.39 (s, 1H), 7.38 (s, 2H), 7.37 – 7.30 (m, 1H), 5.91 – 5.85 (m, 1H), 5.18 – 5.14 (m, 2H), 4.14 – 4.06 (m, 2H), 3.69 (t, J = 5.8 Hz, 2H), 2.47 (ttt, J = 5.7, 2.8, 1.3 Hz, 2H).

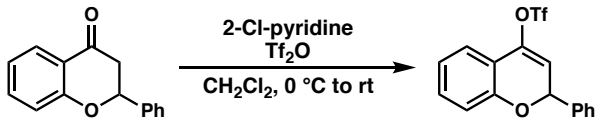
^{13}C NMR (101 MHz, d_3-MeCN, 65 °C): δ 156.2, 148.4, 138.5, 129.7, 129.2, 129.0, 117.4, 68.3, 43.1, 41.9, 29.0.

^{19}F NMR (282 MHz, $CDCl_3$): δ -71.7.

FTIR (NaCl, thin film, cm^{-1}): 3035, 2953, 1714, 1418, 1366, 1281, 1211, 1142, 1116, 1065, 872, 766, 698, 611.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{14}H_{14}F_3NO_5S$ $[M+H]^+$: 366.0623; found: 366.0613.

2-phenyl-2*H*-chromen-4-yl trifluoromethanesulfonate (77)



To a flame dried, N_2-filled round bottom flask was added 2-phenylchroman-4-one (500 mg, 2.9 mmol, 1.0 equiv), 2-chloropyridine (304 mg, 2.7 mmol, 1.2 equiv), and CH_2Cl_2 (8 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (0.45 mL, 2.7 mmol, 1.2 equiv) was added. The reaction was allowed to reach room temperature and continued to stir overnight. The reaction was then cooled to 0 °C, saturated aq. $NaHCO_3$ was slowly added until gas evolution ceased, and then H_2O (25 mL) was added. The crude mixture was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 4% EtOAc/hexanes) to yield 421 mg (53% yield) of a pale solid.

R_f = 0.60 (silica, 10% Et_2O/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49 – 7.44 (m, 2H), 7.44 – 7.35 (m, 3H), 7.30 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.26 (td, *J* = 8.1, 7.7, 1.6 Hz, 1H), 6.99 (td, *J* = 7.6, 1.1 Hz, 1H), 6.86 (dd, *J* = 8.1, 1.0 Hz, 1H), 6.12 (d, *J* = 3.8 Hz, 1H), 5.85 (d, *J* = 3.8 Hz, 1H).

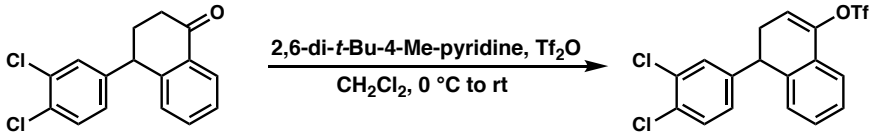
^{13}C NMR (101 MHz, $CDCl_3$): δ 153.9, 143.2, 138.8, 131.9, 129.2, 129.0, 127.1, 121.70, 121.67, 118.5 (q, $J_{C\text{-}F}$ = 320.5 Hz), 116.6, 116.4, 113.1, 77.4.

^{19}F NMR (282 MHz, $CDCl_3$): δ -73.4.

FTIR (NaCl, thin film, cm^{-1}): 3068, 3036, 1667, 1607, 1485, 1455, 1428, 1354, 1248, 1222, 1139, 1032, 935, 883, 858, 758, 698.

HRMS (FAB, *m/z*): calc'd for $C_{16}H_{11}F_3O_4S$ $[M+\cdot]^+$: 356.0330; found: 356.0304.

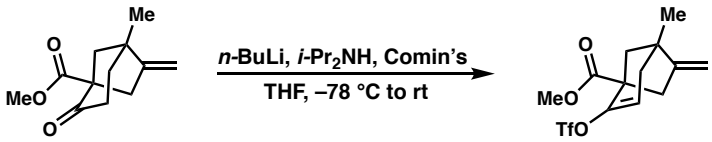
4-(3,4-dichlorophenyl)-3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (78)



To a round bottom flask was added 4-(3,4-dichlorophenyl)-3,4-dihydronaphthalen-1(2*H*)-one (1.46 g, 5.0 mmol, 1.0 equiv), 2,6-di-*tert*-butyl-4-methylpyridine (1.13 g, 5.5 mmol, 1.1 equiv), and CH_2Cl_2 (15 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (1.0 mL, 6.0 mmol, 1.2 equiv) was added. The reaction was allowed to reach room temperature and stirred for 30 minutes before being concentrated. The reaction mixture was then suspended in hexanes, filtered over a plug of Celite, and eluted with additional hexanes. The solution was concentrated and the product was purified by column chromatography (silica, 2% Et_2O/hexanes) to yield 2.09 g (99% yield) of a colorless oil.

R_f = 0.23 (silica, hexanes, $KMnO_4$).
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.39 (d, *J* = 8.3 Hz, 1H), 7.35 (tdd, *J* = 7.7, 1.4, 0.6 Hz, 1H), 7.32 – 7.26 (m, 2H), 7.03 (ddd, *J* = 8.3, 2.2, 0.5 Hz, 1H), 6.94 – 6.89 (m, 1H), 5.97 (t, *J* = 4.8 Hz, 1H), 4.18 (t, *J* = 7.9 Hz, 1H), 2.89 (ddd, *J* = 17.4, 7.4, 4.8 Hz, 1H), 2.72 (ddd, *J* = 17.3, 8.6, 4.9 Hz, 1H).
^{13}C NMR (101 MHz, $CDCl_3$): δ 146.2, 143.2, 137.4, 132.8, 131.2, 130.8, 130.3, 130.0, 128.7, 128.4, 127.9, 127.7, 121.9, 118.7 (q, $J_{C\text{-}F}$ = 320.4 Hz), 116.0, 42.4, 30.8.
^{19}F NMR (282 MHz, $CDCl_3$): δ -73.5.
FTIR (NaCl, thin film, cm^{-1}): 1658, 1470, 1422, 1249, 1213, 1140, 1066, 1019, 895, 765, 612.
HRMS (EI, *m/z*): calc'd for $C_{17}H_{11}Cl_2F_3O_3S$ [M+·]$^+$: 421.9758; found: 421.9755.

methyl (1*s*,5*r*)-5-methyl-6-methylene-2-(((trifluoromethyl)sulfonyl)oxy)bicyclo[3.2.1]oct-2-ene-1-carboxylate (79)



To a flame dried, N_2 filled round bottom flask was added methyl (1*s*,5*r*)-5-methyl-6-methylene-2-oxobicyclo[3.2.1]octane-1-carboxylate (670 mg, 3.0 mmol, 1 equiv) and THF (15 mL). The reaction was cooled to –78 °C (dry ice/acetone) before LDA (0.75M in THF, 4.8 mL, 3.6 mmol, 1.2 equiv) was added via cannula. The reaction mixture was stirred for 30 minutes before Comin's reagent (1M in THF, 3.45 mL, 3.45 mmol, 1.15 equiv) was added via cannula. After 1 hour, the reaction was quenched by addition of saturated aq. $NaHCO_3$ (20 mL) and warmed to room

temperature. The crude mixture was extracted with Et_2O (3 x 15 mL) and the combined organic layers were dried over $MgSO_4$, filtered and concentrated. The product was purified by column chromatography (silica, 5% EtOAc/hexanes) to yield 865 mg (81% yield) of **S1** as a clear oil.

R_f = 0.54 (silica, 10% EtOAc/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.63 (dd, *J* = 4.9, 2.6 Hz, 1H), 5.02 (ddd, *J* = 2.5, 1.7, 0.8 Hz, 1H), 4.96 (dd, *J* = 3.0, 1.9 Hz, 1H), 3.76 (s, 3H), 3.11 – 2.92 (m, 2H), 2.37 (dd, *J* = 17.3, 2.7 Hz, 1H), 2.17 (ddd, *J* = 11.0, 2.7, 0.8 Hz, 1H), 2.11 – 2.02 (m, 1H), 1.96 (dd, *J* = 11.0, 1.5 Hz, 1H), 1.26 (s, 3H).

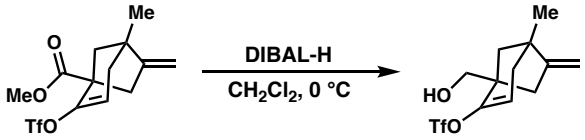
^{13}C NMR (101 MHz, $CDCl_3$): δ 171.1, 155.2, 149.6, 120.0 (q, J_{C-F} = 319.9 Hz), 116.5, 107.7, 52.8, 52.6, 48.2, 44.7, 42.9, 41.9, 23.9.

^{19}F NMR (282 MHz, $CDCl_3$): δ -74.4.

FTIR (NaCl, thin film, cm^{-1}): 2959, 1744, 1420, 1299, 1249, 1209, 1142, 1071, 1029, 265, 623.

HRMS (FAB, *m/z*): calc'd for $C_{13}H_{15}F_3O_3S$ $[M+NH_4]^+$: 358.0931; found: 358.0924.

(1*r*,5*r*)-1-(hydroxymethyl)-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-2-yl trifluoromethanesulfonate (80)



To a flame dried, N_2 filled round bottom flask was added **S1** (783 mg, 2.3 mmol, 1 equiv) and CH_2Cl_2 (23 mL). The reaction was cooled to 0 °C before DIBAL (1.23 mL, 6.9 mmol, 3 equiv) was added slowly. After 45 minutes, the reaction was quenched by addition of 1M HCl (6 mL) and warmed to room temperature. The crude mixture was diluted with water (20 mL) and extracted with CH_2Cl_2 (3 x 15 mL). The combined organic layers were washed with saturated aq. $NaHCO_3$ (30 mL), then brine (30 mL), and dried over $MgSO_4$, filtered and concentrated. The product was purified by column chromatography (silica, 10% to 20% EtOAc/hexanes) to yield 670 mg (93% yield) of **S2** as a clear oil.

R_f = 0.36 (silica, 20% EtOAc/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.61 (dd, *J* = 4.7, 2.7 Hz, 1H), 4.97 (ddd, *J* = 2.4, 1.4, 0.7 Hz, 1H), 4.94 (dd, *J* = 3.0, 1.7 Hz, 1H), 3.99 (dd, *J* = 11.3, 5.3 Hz, 1H), 3.59 (dd, *J* = 11.3, 5.7 Hz, 1H), 2.78 (ddt, *J* = 15.8, 3.2, 1.7 Hz, 1H), 2.41 – 2.29 (m, 2H), 2.08 – 1.98 (m, 2H), 1.74 – 1.67 (m, 2H), 1.25 (s, 3H).

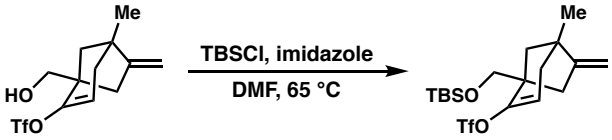
^{13}C NMR (101 MHz, $CDCl_3$): δ 156.6, 153.1, 118.7 (q, J_{C-F} = 319.8 Hz), 117.2, 107.1, 64.5, 48.4, 47.4, 44.3, 43.1, 42.3, 24.4.

^{19}F NMR (282 MHz, $CDCl_3$): δ -74.2.

FTIR (NaCl, thin film, cm^{-1}): 3390 (br), 3076, 2959, 2880, 1668, 1416, 1211, 1142, 1030, 871, 621.

HRMS (FAB, *m/z*): calc'd for $C_{11}H_{11}F_3O_3S$ $[M+H]^+$: 330.0981; found: 330.0981.

(1*r*,5*r*)-1-(((*tert*-butyldimethylsilyl)oxy)methyl)-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-2-yl trifluoromethanesulfonate (81)



To a round bottom flask was added **S2** (576 mg, 1.8 mmol, 1 equiv), imidazole (251 mg, 3.7 mmol, 2 equiv), DMF (18 mL), and TBSCl (333 mg, 2.2 mmol, 1.2) equiv). The reaction was heated to 65 °C for 12 hours, cooled to room temperature and quenched by addition of saturated aq. NH_4Cl (20 mL). The crude mixture was extracted with EtOAc (3 x 20 mL, then the combined organic layers were washed with saturated aq. $NaHCO_3$ (30 mL), then saturated aq. NH_4Cl (3 x 30 mL), dried over $MgSO_4$, filtered and concentrated. The product was purified by column chromatography (silica, hexanes to 3% EtOAc/Hexanes) to yield 738 mg (94% yield) of a white solid.

R_f = 0.27 (silica, hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.55 (dd, *J* = 4.7, 2.7 Hz, 1H), 4.95 (ddd, *J* = 2.5, 1.5, 0.8 Hz, 1H), 4.92 (dd, *J* = 3.1, 1.7 Hz, 1H), 3.90 (d, *J* = 10.1 Hz, 1H), 3.51 (d, *J* = 10.1 Hz, 1H), 2.69 (ddt, *J* = 15.8, 3.1, 1.6 Hz, 1H), 2.43 – 2.35 (m, 1H), 2.32 (dd, *J* = 17.1, 2.7 Hz, 1H), 2.06 – 1.97 (m, 1H), 1.91 (dd, *J* = 11.0, 2.8 Hz, 1H), 1.69 (dd, *J* = 10.9, 1.5 Hz, 1H), 1.24 (s, 3H), 0.89 (s, 9H), 0.05 (s, 6H).

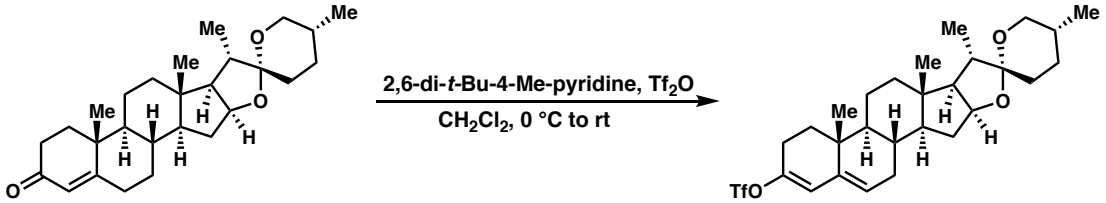
^{13}C NMR (101 MHz, $CDCl_3$): δ 157.3, 153.6, 120.1 (q, J_{C-F} = 319.3 Hz), 116.3, 106.7, 64.0, 48.4, 47.6, 43.8, 43.0, 42.4, 26.0, 24.5, 18.5, -5.5.

^{19}F NMR (282 MHz, $CDCl_3$): δ -74.4.

FTIR (NaCl, thin film, cm^{-1}): 3076, 2957, 2860, 1668, 1473, 1418, 1246, 1211, 1144, 1101, 1031, 874, 840, 778, 620.

HRMS (FAB, *m/z*): calc'd for $C_{18}H_{29}F_3O_4S$ $[M+H]^+$: 427.1581; found: 427.1568.

5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,-6',7,8,8a,8b,9,11a,12,12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]furan-10,2'-pyran]-4-yl trifluoromethanesulfonate (82)



To a round bottom flask was added (5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,[12]a*S*,12b*S*)-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,12a,12b-octadecahydrospiro[naphtha[2',1':4-,5]indeno[2,1-*b*]furan-10,2'-pyran]-4(3*H*)-one (661 mg, 1.8 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (395 mg, 2.16 mmol, 1.2 equiv), and CH_2Cl_2 (5.0 mL). The reaction was cooled to 0 °C and trifluoromethanesulfonic anhydride (296 μL, 1.98 mmol, 1.1 equiv) was added. The reaction was stirred at room temperature overnight, then washed with saturated aq. $NaHCO_3$ (50 mL) and extracted with CH_2Cl_2 (2 x 100 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 5 to 10% Et_2O/hexanes) to yield 488 mg (50% yield) of a white solid.

R_f = 0.40 (silica, 10% Et_2O/hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –125° (c = 1.0, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.99 (d, *J* = 2.2 Hz, 1H), 5.57 (dd, *J* = 5.1, 2.9 Hz, 1H), 4.42 (ddd, *J* = 8.6, 7.5, 6.3 Hz, 1H), 3.47 (ddd, *J* = 10.8, 4.6, 2.0 Hz, 1H), 3.37 (t, *J* = 10.9 Hz, 1H), 2.63 – 2.48 (m, 1H), 2.40 – 2.30 (m, 1H), 2.23 (dt, *J* = 18.8, 5.2 Hz, 1H), 1.99 (ddd, *J* = 11.8, 7.5, 5.4 Hz, 1H), 1.95 – 1.51 (m, 11H), 1.51 – 1.39 (m, 2H), 1.32 (ddd, *J* = 13.7, 11.9, 6.4 Hz, 2H), 1.26 – 1.11 (m, 2H), 1.09 – 0.99 (m, 1H), 0.99 (s, 6H), 0.81 (s, 3H), 0.79 (d, *J* = 6.3 Hz, 3H).

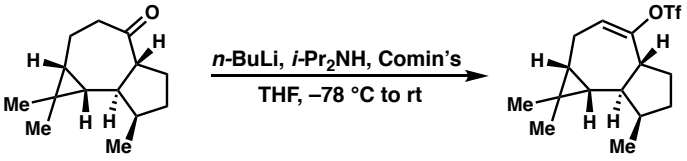
^{13}C NMR (101 MHz, $CDCl_3$): δ 147.1, 138.2, 128.1, 120.6, 118.7 (q, J_{C-F} = 319.9 Hz), 109.5, 80.9, 67.0, 62.2, 56.6, 47.8, 41.8, 40.5, 39.8, 35.0, 33.9, 32.2, 31.9, 31.5, 31.3, 30.4, 28.9, 25.7, 21.2, 18.8, 17.3, 16.5, 14.7.

^{19}F NMR (282 MHz, $CDCl_3$): δ -73.8.

FTIR (NaCl, thin film, cm^{-1}): 3054, 2947, 2306, 1640, 1456, 1380, 1266, 1214, 1140, 1051, 919, 829, 740.

HRMS (FAB, *m/z*): calc'd for $C_{28}H_{40}F_3O_5S$ $[M+H]^+$: 545.2549; found: 545.2536.

(1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulen-4-yl trifluoromethanesulfonate (83)



To a round bottom flask was added diisopropyl amine (337 µL, 2.4 mmol, 1.2 equiv) and THF (6 mL). The solution was cooled to 0 °C, then *n*-butyllithium (960 µL, 2.5 M in hexanes, 2.4 mmol, 1.2 equiv) was added and stirred for 30 minutes before being cooled to –78 °C. (1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-1,1,7-Trimethyldecahydro-4*H*-cyclopropa[*e*]azulen-4-one (412 mg, 2.0 mmol, 1.0 equiv) was added and stirred for 30 minutes before N-(5-chloro-2-pyridyl)bis(trifluoromethanesulfonimide) (942 mg, 2.4 mmol, 1.2 equiv) was added in one portion. The reaction was allowed to reach room temperature and stir overnight. The reaction was quenched with H_2O and extracted with Et_2O (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, hexanes) to yield 386 mg (57% yield) of a colorless oil which solidified in the freezer.

$\mathbf{R_f}$ = 0.49 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –93° (c = 1.0, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.74 (ddd, *J* = 9.3, 2.9, 2.1 Hz, 1H), 2.79 (tdd, *J* = 11.3, 5.4, 2.0 Hz, 1H), 2.29 (dddd, *J* = 17.3, 9.3, 7.0, 0.8 Hz, 1H), 2.24 – 2.11 (m, 1H), 2.11 – 1.90 (m, 3H), 1.70 (td, *J* = 11.7, 8.4 Hz, 1H), 1.56 – 1.41 (m, 1H), 1.24 (dtd, *J* = 13.1, 8.5, 4.3 Hz, 1H), 1.05 (d, *J* =

1.1 Hz, 6H), 0.97 (ddd, J = 10.1, 9.3, 7.0 Hz, 1H), 0.92 (d, J = 7.2 Hz, 3H), 0.65 (dd, J = 11.5, 9.2 Hz, 1H).

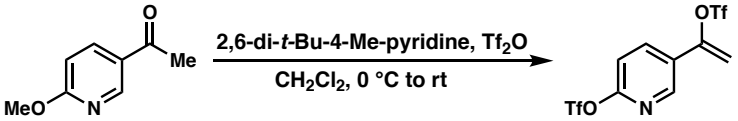
^{13}C NMR (101 MHz, $CDCl_3$): δ 154.6, 120.1, 118.7 (q, J_{C-F} = 319.9 Hz), 48.0, 43.1, 34.4, 32.0, 29.8, 28.5, 25.7, 25.6, 20.3, 18.7, 18.0, 15.3.

^{19}F NMR (282 MHz, $CDCl_3$): δ -74.3.

FTIR (NaCl, thin film, cm^{-1}): 2957, 2872, 1672, 1457, 1415, 1246, 1208, 1145, 984, 941, 865.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{21}F_3O_3S$ $[M+\cdot]^+$: 338.1164; found: 338.1164.

1-(6-(((trifluoromethyl)sulfonyl)oxy)pyridin-3-yl)vinyl trifluoromethanesulfonate (84)



To a round bottom flask was added 1-(6-methoxypyridin-3-yl)ethan-1-one (756 mg, 5.0 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (2.26 g, 11 mmol, 2.2 equiv), and CH_2Cl_2 (15 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (2.0 mL, 12.0 mmol, 2.4 equiv) was added. The reaction was allowed to reach room temperature and stir overnight. The reaction was then cooled to 0 °C and saturated aq. $NaHCO_3$ was added slowly until gas evolution ceased, then H_2O (25 mL) was added. The crude mixture was extracted with Et_2O (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 20% Et_2O/hexanes) to yield 544 mg (27% yield) of a light orange oil.

R_f = 0.33 (silica, 30% Et_2O/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.59 (dd, J = 2.6, 0.7 Hz, 1H), 8.03 (dd, J = 8.6, 2.6 Hz, 1H), 7.30 – 7.23 (m, 1H), 5.75 (d, J = 4.5 Hz, 1H), 5.61 (d, J = 4.6 Hz, 1H).

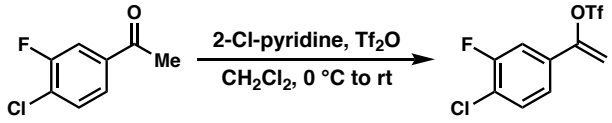
^{13}C NMR (101 MHz, $CDCl_3$): δ 156.6, 149.0, 145.9, 138.0, 129.3, 118.7 (q, J_{C-F} = 320.6 Hz), 118.6 (q, J_{C-F} = 320.4 Hz), 115.4, 108.0.

^{19}F NMR (282 MHz, $CDCl_3$): δ -72.8, -73.3.

FTIR (NaCl, thin film, cm^{-1}): 1648, 1588, 1474, 1427, 1212, 1138, 943, 890, 819.

HRMS (TOF-ESI, *m/z*): calc'd for $C_9H_5F_6O_6NS_2$ $[M+H]^+$: 401.9541; found: 401.9551.

1-(4-chloro-3-fluorophenyl)vinyl trifluoromethanesulfonate (85)



To a flame dried, N_2 filled round bottom flask was added 1-(4-chloro-3-fluorophenyl)vinyl trifluoromethanesulfonate (500 mg, 2.9 mmol, 1.0 equiv), 2-chloropyridine (428 mg, 3.8 mmol, 1.3 equiv), and CH_2Cl_2 (10 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (0.58 mL, 3.5 mmol, 1.2 equiv) was added. The reaction was allowed to reach room temperature and continued to stir overnight. The reaction was then cooled to 0 °C and saturated aq. $NaHCO_3$ was added slowly until gas evolution ceased, then H_2O (25 mL) was added. The crude mixture was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, hexanes) to yield 434 mg (49% yield) of a light yellow oil.

R_f = 0.31 (silica, hexanes, UV).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.46 (dd, *J* = 8.4, 7.3 Hz, 1H), 7.32 (dd, *J* = 9.6, 2.1 Hz, 1H), 7.29 (ddd, *J* = 8.4, 2.1, 0.9 Hz, 1H), 5.64 (d, *J* = 4.3 Hz, 1H), 5.47 (d, *J* = 4.3 Hz, 1H).

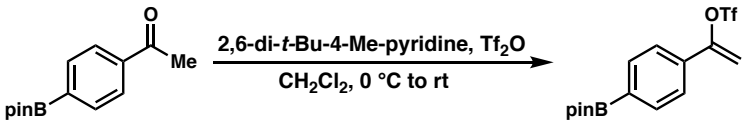
^{13}C NMR (101 MHz, $CDCl_3$): 158.3 (d, $J_{C\text{-}F}$ = 250.3 Hz), 151.3 (d, $J_{C\text{-}F}$ = 2.7 Hz), 132.6 (d, $J_{C\text{-}F}$ = 7.2 Hz), 131.4, 123.5 (d, $J_{C\text{-}F}$ = 17.7 Hz), 121.8 (d, $J_{C\text{-}F}$ = 3.9 Hz), 118.6 (q, $J_{C\text{-}F}$ = 320.3 Hz), 113.8 (d, $J_{C\text{-}F}$ = 23.7 Hz), 106.0.

^{19}F NMR (282 MHz, $CDCl_3$): δ -73.5, -113.2 (dd, $J_{F\text{-}H}$ = 9.3, 7.3 Hz).

FTIR (NaCl, thin film, cm^{-1}): 1647, 1575, 1492, 1423, 1296, 1244, 1216, 1141, 1080, 955, 916, 803, 607.

HRMS (FAB, *m/z*): calc'd for $C_9H_5ClF_4O_3S$ $[M+\cdot]^+$: 303.9584; found: 303.9592.

1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)vinyl trifluoromethanesulfonate (86)



To a round bottom flask was added 1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)ethan-1-one (984 mg, 4.0 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (904 mg,

4.4 mmol, 1.1 equiv), and CH_2Cl_2 (12 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (808 μL, 4.8 mmol, 1.2 equiv) was added. The reaction was allowed to reach room temperature and continued to stir overnight. The reaction was concentrated and the product was purified by column chromatography (silica, 5% EtOAc/hexanes) to yield 742 mg (49% yield) of a blue oil.

R_f = 0.51 (silica, 10% Et_2O/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 – 7.81 (m, 2H), 7.56 – 7.51 (m, 2H), 5.67 (d, *J* = 4.0 Hz, 1H), 5.41 (d, *J* = 4.0 Hz, 1H), 1.35 (s, 12H).

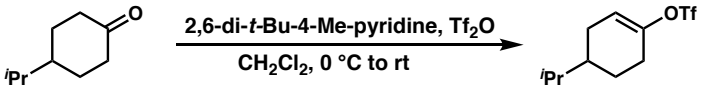
^{13}C NMR (101 MHz, $CDCl_3$): δ 153.6, 135.3, 134.4, 124.5, 118.6 (q, $J_{C\text{-}F}$ = 320.2 Hz), 105.1, 84.3, 25.0. *(Note: carbon bonded to boron not observed.)*

^{19}F NMR (282 MHz, $CDCl_3$): δ -73.7.

FTIR (NaCl, thin film, cm^{-1}): 2981, 1646, 1612, 1423, 1402, 1362, 1225, 1143, 1096, 939, 829, 660, 605.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{15}BF_3O_5S$ $[M+\cdot]^+$: 378.0920; found: 378.0946.

4-isopropylcyclohex-1-en-1-yl trifluoromethanesulfonate (69)



To a flame dried, N_2-filled round bottom flask was added 4-isopropylcyclohexan-1-one (1.8 g, 12.5 mmol, 1.0 equiv), 2,6-ditertbutyl-4-methylpyridine (3.0 g, 14.4 mmol, 1.15 equiv), and CH_2Cl_2 (83 mL). The reaction was cooled to 0 °C before trifluoromethanesulfonic anhydride (2.3 mL, 2.7 mmol, 1.2 equiv) was added. The reaction was allowed to reach room temperature and continued to stir overnight. The reaction was then cooled to 0 °C, saturated aq. $NaHCO_3$ was slowly added until gas evolution ceased, and then H_2O (25 mL) was added. The crude mixture was extracted with CH_2Cl_2 (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, hexanes) to yield 2.3 g (68% yield) of **27** as a clear oil.

R_f = 0.49 (silica, hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.74 (dt, *J* = 5.2, 2.6 Hz, 1H), 2.46 – 2.34 (m, 1H), 2.34 – 2.25 (m, 1H), 2.25 – 2.14 (m, 1H), 1.98 – 1.84 (m, 2H), 1.61 – 1.49 (m, 1H), 1.49 – 1.29 (m, 2H), 0.91 (d, *J* = 3.0 Hz, 3H), 0.90 (d, *J* = 3.0 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 149.4, 118.6 (q, J_{C-F} = 320.1 Hz), 118.3, 39.0, 31.7, 28.1, 27.4, 26.2, 20.0, 19.7.

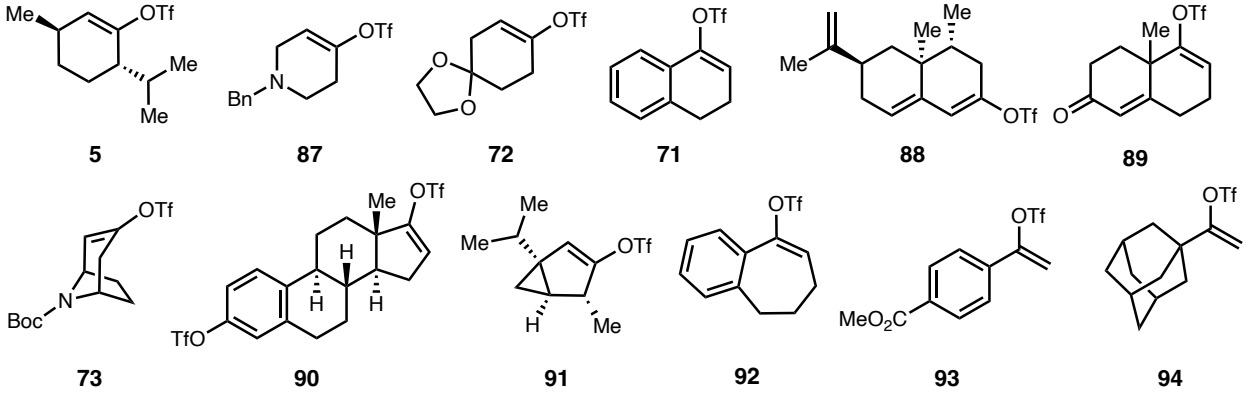
^{19}F NMR (282 MHz, $CDCl_3$): δ -73.9.

FTIR (NaCl, thin film, cm^{-1}): 2962, 2933, 2876, 1693, 1418, 1248, 1209, 1144, 1053, 1022, 879, 853, 615.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{15}F_3O_3S$ [M+·]$^+$: 272.0694; found: 272.0681.

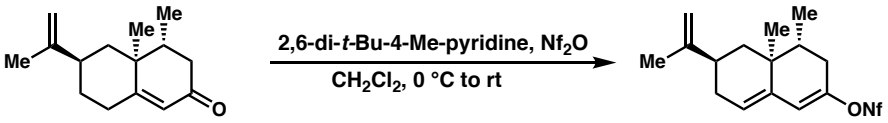
Other Enol Triflates Prepared from Literature

The following enol triflates were prepared according to literature procedures. [40–49]



b. Enol Nonaflate Preparation

(4*R*,4a*S*,6*R*)-4,4a-dimethyl-6-(prop-1-en-2-yl)-3,4,4a,5,6,7-hexahydronaphthalen-2-yl 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate (95)



To a round bottom flask was added (4*S*,4a*R*,6*S*)-4,4a-dimethyl-6-(prop-1-en-2-yl)-4,4a,5,6,7,8-hexahydronaphthalen-2(3*H*)-one (174 mg, 0.8 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (312 mg, 0.9 mmol, 1.1 equiv), and CH_2Cl_2 (4 mL). The reaction was cooled to 0 °C before nonafluorobutanesulfonic anhydride (465 mg, 0.8 mmol, 1.0 equiv) was added. The reaction was allowed to reach room temperature and continued to stir for 2 hours. The reaction

was diluted with hexanes, filtered, and concentrated. The product was purified by column chromatography (silica, hexanes) to yield 226 mg (56% yield) of (**S5)** as a colorless oil.

R*f* = 0.22 (silica, hexanes, UV).

$[\boldsymbol{\alpha}]_{\boldsymbol{D}}^{\mathbf{25}}$ = –66° (c = 0.5, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.04 (s, 1H), 5.63 (dd, *J* = 5.3, 2.7 Hz, 1H), 4.76 (pd, *J* = 1.9, 1.3 Hz, 2H), 2.50 – 2.36 (m, 1H), 2.36 – 2.29 (m, 3H), 2.26 (td, *J* = 5.4, 1.4 Hz, 1H), 1.98 (ddd, *J* = 18.9, 11.4, 2.3 Hz, 1H), 1.79 – 1.65 (m, 5H), 1.18 (t, *J* = 12.7 Hz, 1H), 0.96 (d, *J* = 6.8 Hz, 3H), 0.93 (s, 3H).

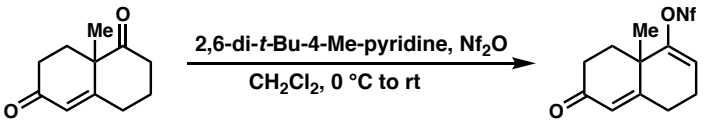
^{13}C NMR (101 MHz, $CDCl_3$): δ 149.6, 147.1, 138.5, 128.2, 120.5, 109.3, 39.7, 39.3, 37.1, 35.9, 34.3, 31.4, 30.3, 20.8, 17.3, 14.5. (*Note: nonaflate carbons omitted due to low intensity resulting from C-F splitting*)

^{19}F NMR (282 MHz, $CDCl_3$): δ -80.57 (tt, *J* = 9.8, 2.3 Hz), -109.77 – -109.94 (m), -120.90 (dddt, *J* = 15.8, 9.7, 6.3, 3.3 Hz), -125.69 – -125.92 (m).

FTIR (NaCl, thin film, cm^{-1}): 2969, 1644, 1416, 1238, 1142, 1058, 912.

HRMS (EI, *m/z*): calc'd for $C_{19}H_{20}F_9O_3S$ $[M-H]^+$: 499.0989; found: 499.0965.

8a-methyl-6-oxo-3,4,6,7,8,8a-hexahydronaphthalen-1-yl 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate (96)



To a round bottom flask was added 8a-methyl-3,4,8,8a-tetrahydronaphthalene-1,6(2*H*,7*H*)-dione (142 mg, 0.8 mmol, 1.0 equiv), 2,6-di-tert-butyl-4-methylpyridine (312 mg, 0.9 mmol, 1.1 equiv), and CH_2Cl_2 (4 mL). The reaction was cooled to 0 °C before nonafluorobutansulfonic anhydride (465 mg, 0.8 mmol, 1.0 equiv) was added. The reaction was allowed to reach room temperature and continued to stir for 2 hours. The reaction was diluted with hexanes, filtered, and concentrated. The product was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield 270 mg (73% yield) of (**S6)** as a white solid.

R$_f$ = 0.32 (silica, 25% Et_2O/hexanes, UV).

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.15 (d, *J* = 2.3 Hz, 1H), 5.89 – 5.82 (m, 1H), 2.81 (ddd, *J* = 15.4, 7.3, 6.2 Hz, 1H), 2.74 – 2.35 (m, 5H), 2.07 (ddd, *J* = 13.6, 5.9, 1.6 Hz, 1H), 1.75 – 1.61 (m, 1H), 1.25 (s, 3H).

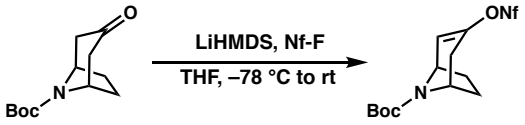
^{13}C NMR (101 MHz, $CDCl_3$): δ 213.0, 148.2, 136.4, 127.4, 119.4, 44.7, 35.2, 28.9, 25.1, 24.9, 22.7. (*Note: nonaflate carbons omitted due to low intensity resulting from C-F splitting*)

^{19}F NMR (282 MHz, $CDCl_3$): δ -80.57 (tt, *J* = 9.8, 2.3 Hz), -109.67 – -109.85 (m), -120.88 (dtd, *J* = 14.8, 7.1, 6.5, 4.2 Hz), -125.68 – -125.92 (m).

FTIR (NaCl, thin film, cm^{-1}): 2969, 2936, 1715, 1664, 1420, 1353, 1203, 1144, 1061, 880.

HRMS (EI, *m/z*): calc'd for $C_{15}H_{13}F_9O_4S$ [M+·]$^+$: 460.0391; found: 460.0375.

***tert*-butyl (1*r*,5*s*)-3-(((perfluorobutyl)sulfonyl)oxy)-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (97)**



To a flame dried round-bottom flask under an inert atmosphere was added *tert*-butyl (1*R*,5*S*)-3-oxo-8-azabicyclo[3.2.1]octane-8-carboxylate (1.17 g, 5.0 mmol, 1.0 equiv). THF (9 mL) was added and the reaction was cooled to –78 °C. LiHMDS (5.5 mL, 1 M in THF, 5.5 mmol, 1.1 equiv) was added dropwise and allowed to stir for 30 minutes before perfluorobutanesulfonylfluoride (1.88 g, 5.25 mmol, 1.05 equiv) was added in one portion. The reaction was allowed to reach room temperature and stir overnight. The reaction was then quenched with saturated aq. NH_4Cl (50 mL) and extracted with Et_2O (2 x 50 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated. The product was purified by column chromatography (silica, 10-20% Et_2O/hexanes) to yield 2.1 g (95% yield) of (**S7)** as an off white solid.

R_f = 0.59 (silica, 75% Et_2O/hexanes, anisaldehyde (blue)).

^{1}H NMR (400 MHz, d_3-MeCN, 65 °C): δ 6.19 (ddd, *J* = 5.8, 1.9, 1.1 Hz, 1H), 4.53 – 4.45 (m, 1H), 4.44 – 4.36 (m, 1H), 3.08 – 2.95 (m, 1H), 2.23 (dddd, *J* = 13.6, 7.4, 6.3, 1.7 Hz, 1H), 2.16 (dt, *J* = 17.0, 1.2 Hz, 1H), 2.04 – 1.96 (m, 2H), 1.81 – 1.69 (m, 1H), 1.45 (s, 9H).

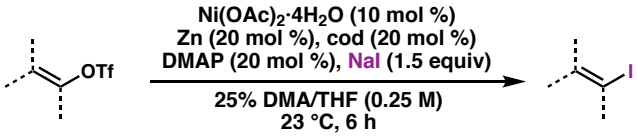
^{13}C NMR (101 MHz, d_3-MeCN, 65 °C): δ 154.9, 149.1, 125.3, 80.9, 53.6, 53.5, 37.6, 35.2, 30.4, 28.7. (*Note: nonaflate carbons omitted due to low intensity resulting from C-F splitting*)

^{19}F NMR (376 MHz, d_3-MeCN, 65 °C): δ -81.46 (tt, J = 9.7, 2.8 Hz), -109.99 (ddp, J = 16.8, 10.7, 2.7 Hz), -121.10 – -121.26 (m), -125.91 – -126.07 (m). (*Note: not standardized with internal C_6F_6*).

FTIR (NaCl, thin film, cm^{-1}): 3188, 3076, 2981, 1697, 1416, 1326, 1243, 1064, 875.

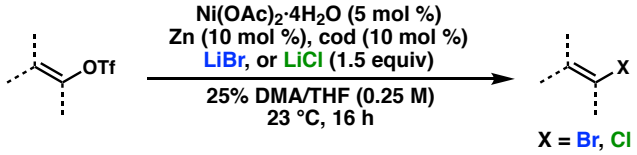
HRMS (EI, *m/z*): calc'd for $C_{16}H_{19}F_9O_5SN$ $[M+H]^+$: 508.0843; found: 508.0840.

4. Ni-Catalyzed Halogenation



a. Method A: Ni(II)+Zn Enol Triflate Iodination on 0.3 mmol scale.

A 1-dram vial equipped with a stir bar was brought into an N_2- filled glovebox. The vial was charged with $Ni(OAc)_2$•$4H_2O$ (7.5 mg, 0.03 mmol, 0.1 equiv), Zn (3.9 mg, 0.06 mmol, 0.2 equiv), cod (7.4 µL, 0.06 mmol, 0.2 equiv), and NaI (67.5 mg, 0.45 mmol, 1.5 equiv). Anhydrous DMA (0.3 mL) and THF (0.9 mL) were added in a 1:3 ratio (0.25 M overall), resulting in a yellow-green color. Enol triflate (0.3 mmol, 1.0 equiv) was added neat. The vial was sealed with a Teflon cap and brought out of the glovebox to stir on the bench (600 rpm) for 6 hours at room temperature (23 °C). The reaction was quenched by addition of water, then NH_4Cl and Et_2O were added. The organic phase was separated and extracted with 2 x 10 mL Et_2O, then washed once with brine (20 mL). The combined layers were dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product. Where appropriate, yields are adjusted to account for purity by ^{1}H NMR (up to 5% protodetriflation observed).



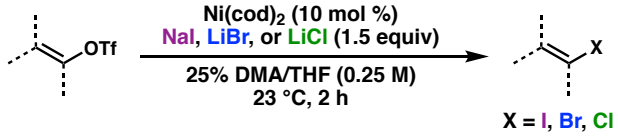
b. Method B: Ni(II)+Zn Enol Triflate Bromination and Chlorination on 0.3 mmol scale.

A 1-dram vial equipped with a stir bar was brought into an N_2- filled glovebox. The vial was charged with $Ni(OAc)_2$•$4H_2O$ (3.7 mg, 0.015 mmol, 0.05 equiv), Zn (2.0 mg, 0.03 mmol, 0.1 equiv), cod (3.7 µL, 0.03 mmol, 0.1 equiv), and either LiBr (39.1 mg, 0.45 mmol, 1.5 equiv) or LiCl (19.1 mg, 0.45 mmol, 1.5 equiv). Anhydrous DMA (0.3 mL) and THF (0.9 mL) were added

in a 1:3 ratio (0.25 M overall), resulting in a blue color. Enol triflate (0.3 mmol, 1.0 equiv) was added neat. The vial was sealed with a Teflon cap and brought out of the glovebox to stir on the bench (600 rpm) for 16 hours at room temperature (23 °C). The reaction was quenched by addition of water, then NH_4Cl and Et_2O were added. The organic phase was separated and extracted with 2 x 10 mL Et_2O, then washed once with brine (20 mL). The combined layers were dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product. Where appropriate, yields are adjusted to account for purity by ^1H NMR (up to 5% protodetriflation observed).

c. Method B, Procedure 2: Ni(II) Enol Triflate Bromination on 1 mmol scale without use of a glovebox.

To a flame-dried 25 ml pear-shaped round bottomed flask equipped with a stir bar and a rubber septum was added $Ni(OAc)_2•4H_2O$ (0.05 mmol, 0.05 equiv.), Zn dust (0.1 mmol, 0.1 equiv.), and LiBr (1.5 mmol, 1.5 equiv.). The flask was lightly flame dried under vacuum and, after cooling, enol triflate (if solid, 1 mmol, 1 equiv.) was added (should DMAP be required we would recommend adding it at this time). The flask was evacuated and back-filled three times with N_2 (5 minute evacuation cycles). Concomitantly, a 20 ml scintillation vial containing 1,5-cyclooctadiene (ca. 5 ml) was fitted with a rubber septum, sealed with electrical tape, and evacuated and backfilled three times with N_2 (30 second evacuation cycles, caution 1,5-cyclooctadiene is volatile). The reaction flask (under N_2) was then charged with 1,5-cyclooctadiene (12.3 µl, 0.1 mmol, 0.1 equiv), anhydrous DMA (1 ml), THF (3 ml), and enol triflate (if liquid, 1 mmol, 1 equiv). The reaction mixture was allowed to stir (700 rpm) on the bench for 16h at room temperature before it was quenched by the addition of water, saturated aq. NH_4Cl, and Et_2O. The organic phase was separated and the aqueous phase was extracted with 2 x 30 ml Et_2O. The combined organic phases were then washed with brine (50 mL), dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product. Where appropriate, yields are adjusted to account for purity by ^1H NMR (up to 5% protodetriflation observed).

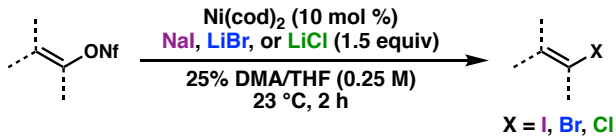


d. Method C, Procedure 1: Ni(0) Enol Triflate Halogenation on 0.3 mmol scale.

A 2-dram vial was equipped with a stir bar and brought into a N_2-filled glovebox. The vial was charged with NaI, LiBr, or LiCl (0.45 mmol, 1.5 equiv) and $Ni(cod)_2$ (8.3 mg, 0.03 mmol, 0.1 equiv). Anhydrous DMA (0.3 mL) and THF (0.9 mL) were added, resulting in a clear yellow solution. Enol triflate (0.3 mmol, 1 equiv) was added in one portion, turning the reaction dark red (NaI) or aqua blue (LiBr or LiCl) over several minutes. The vial was sealed with Teflon cap and brought out of the glovebox. The reaction was allowed to stir on the bench (480 rpm) for two hours at room temperature. Reaction was quenched by addition of water and Et_2O. The organic layer was separated and extracted with 2 x 10 mL Et_2O, then washed once with brine (20 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product.

e. Method C, Procedure 2: Ni(0) Enol Triflate Halogenation on 6.0 mmol scale.

A 100 mL Schlenk flask was equipped with a stir bar and brought into a N_2-filled glovebox. The vial was charged with NaI, LiBr, or LiCl (9.0 mmol, 1.5 equiv) and $Ni(cod)_2$ (166 mg, 0.6 mmol, 0.1 equiv). Anhydrous DMA (6 mL) and THF (18 mL) were added, resulting in a clear yellow solution. Enol triflate (6.0 mmol, 1 equiv) was added in one portion, turning the reaction dark red (NaI) or aqua blue (LiBr or LiCl) over several minutes. The Schlenk flask was sealed with a Kontes valve and brought out of the glovebox. The reaction was allowed to stir on the bench (480 rpm) for two hours at room temperature. Reaction was quenched by addition of water and Et_2O. The organic layer was separated and extracted with 2 x 200 mL Et_2O, then washed once with brine (400 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product.

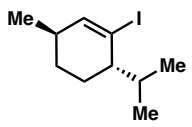


f. Method C, Procedure 3: Enol Nonaflate Halogenation on 0.3 mmol scale.

A 2-dram vial was equipped with a stir bar and brought into a N_2-filled glovebox. The vial was charged with NaI, LiBr, or LiCl (0.45 mmol, 1.5 equiv) and $Ni(cod)_2$ (8.3 mg, 0.03 mmol, 0.1 equiv). Anhydrous DMA (0.3 mL) and THF (0.9 mL) were added, resulting in a clear yellow solution. Enol nonaflate (0.3 mmol, 1 equiv) was added in one portion, turning the reaction dark red (NaI) or aqua blue (LiBr or LiCl) over several minutes. The vial was sealed with Teflon cap and brought out of the glovebox. The reaction was allowed to stir on the bench (480 rpm) for two hours at room temperature. Reaction was quenched by addition of water and Et_2O. The organic layer was separated and extracted with 2 x 10 mL Et_2O, then washed once with brine (20 mL). The combined organic layers were dried with $MgSO_4$, filtered, and concentrated under reduced pressure. The crude reaction was purified by silica gel chromatography to afford the desired product.

g. Characterization of Reaction Products

(3*R*,6*S*)-1-iodo-6-isopropyl-3-methylcyclohex-1-ene (6)



Prepared from (3*R*,6*S*)-6-isopropyl-3-methylcyclohex-1-en-1-yl trifluoromethanesulfonate (85.9 mg, 0.3 mmol) and sodium iodide (68 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (75.6 mg, 95% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 99% pure by mass (1% protodetriflation). The yield is adjusted accordingly (95 x 0.99 = 95% yield).

Prepared from (3*R*,6*S*)-6-isopropyl-3-methylcyclohex-1-en-1-yl trifluoromethanesulfonate (1.70 g, 6.0 mmol) and sodium iodide (1.3 g, 9.0 mmol) according to Method C, Procedure 2. The crude residue was purified by column chromatography (silica, pentane) to yield (1.12 g, 71% yield) as a colorless oil.

$\mathbf{R}_f$ = 0.79 (silica, pentane, $KMnO_4$).

$[\boldsymbol{a}]_D^{25}$ = –47° (c = 0.5, $CHCl_3$).

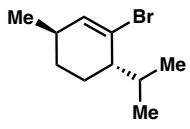
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.36 (q, *J* = 1.4 Hz, 1H), 2.36 – 2.12 (m, 3H), 1.90 – 1.80 (m, 1H), 1.68 (dddd, *J* = 13.3, 5.9, 4.5, 3.1 Hz, 1H), 1.57 – 1.42 (m, 1H), 1.18 (tdd, *J* = 13.0, 10.1, 3.1 Hz, 1H), 0.97 (d, *J* = 7.0 Hz, 3H), 0.94 (d, *J* = 6.8 Hz, 3H), 0.72 (d, *J* = 6.7 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 146.8, 109.2, 48.7, 35.7, 32.4, 30.9, 23.0, 21.5, 20.5, 15.1.

FTIR (NaCl, thin film, cm^{-1}): 2958, 2868, 1617, 1457, 1367, 1314, 944, 852, 782, 703.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{17}I$ $[M+\cdot]^+$: 264.0375; found: 264.0392.

(3*R*,6*S*)-1-bromo-6-isopropyl-3-methylcyclohex-1-ene (7)



Prepared from (3*R*,6*S*)-6-isopropyl-3-methylcyclohex-1-en-1-yl trifluoromethanesulfonate (85.9 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (51 mg, 78% yield) as a colorless oil. *Note: This compound is volatile.*

Prepared from (3*R*,6*S*)-6-isopropyl-3-methylcyclohex-1-en-1-yl trifluoromethanesulfonate (1.43 g, 5.0 mmol) and lithium bromide (651 mg, 7.5 mmol) according to Method B with the exception that a 50 mL round bottom flask, a large football shaped stir bar, and DMAP were used. The reaction was setup in the glovebox, then sealed with a septa and electrical tape, and finally stirred at 700 rpm for 16 h. The crude residue was purified by column chromatography (silica, pentane) to yield (985 mg, 88% yield) as a colorless oil.

R_f = 0.77 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –26° (c = 1.0, $CHCl_3$).

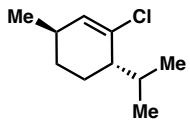
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.99 (td, *J* = 2.0, 0.9 Hz, 1H), 2.39 (ddt, *J* = 13.6, 6.8, 3.4 Hz, 1H), 2.32 (dqd, *J* = 9.7, 3.9, 2.0 Hz, 1H), 2.18 (ddddd, *J* = 10.6, 7.0, 4.9, 3.6, 2.1 Hz, 1H), 1.86 – 1.70 (m, 2H), 1.51 – 1.38 (m, 1H), 1.14 (tdd, *J* = 12.4, 10.1, 2.6 Hz, 1H), 0.98 (d, *J* = 7.1 Hz, 3H), 0.94 (d, *J* = 6.9 Hz, 3H), 0.76 (d, *J* = 6.8 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 137.8, 129.5, 47.0, 33.9, 30.8, 29.7, 23.2, 21.6, 20.3, 15.4.

FTIR (NaCl, thin film, cm^{-1}): 2959, 2930, 2870, 2854, 1634, 1458, 1387, 1318, 949, 851, 791.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{17}Br$ $[M+\cdot]^+$: 216.0514; found: 216.0532.

(3*R*,6*S*)-1-chloro-6-isopropyl-3-methylcyclohex-1-ene (8)



Prepared from (3*R*,6*S*)-6-isopropyl-3-methylcyclohex-1-en-1-yl trifluoromethanesulfonate (85.9 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (38 mg, 73% yield) as a colorless oil. *Note: This compound is volatile.*

R_f = 0.87 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –11° (c = 0.5, $CHCl_3$).

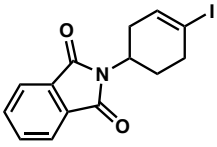
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.66 (td, *J* = 2.1, 1.0 Hz, 1H), 2.40 – 2.25 (m, 1H), 2.25 – 2.06 (m, 2H), 1.80 – 1.62 (m, 2H), 1.41 – 1.27 (m, 1H), 1.11 – 0.96 (m, 1H), 0.91 (d, *J* = 7.1 Hz, 3H), 0.86 (d, *J* = 7.0 Hz, 3H), 0.69 (d, *J* = 6.8 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 136.5, 133.3, 45.8, 32.5, 30.8, 28.2, 22.9, 21.8, 20.3, 15.7.

FTIR (NaCl, thin film, cm^{-1}): 2960, 2870, 1642, 1454, 1368, 957, 851, 812, 727.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{17}Cl$ $[M+\cdot]^+$: 172.1019; found: 172.1032.

2-(4-iodocyclohex-3-en-1-yl)isoindoline-1,3-dione (9)



Prepared from 4-(1,3-dioxoisoindolin-2-yl)cyclohex-1-en-1-yl trifluoromethanesulfonate (113 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, 10 to 25% Et_2O/hexanes) to yield (81 mg, 76% yield) as a white solid. The purity was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (76 x 0.96 = 73% yield).

R_f = 0.40 (silica, 30% Et_2O/hexanes, $KMnO_4$).

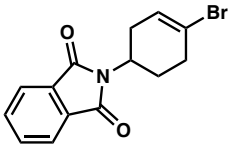
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 – 7.76 (m, 2H), 7.76 – 7.65 (m, 2H), 6.29 (dt, *J* = 6.2, 2.0 Hz, 1H), 4.55 – 4.33 (m, 1H), 3.06 – 2.92 (m, 1H), 2.82 – 2.60 (m, 3H), 2.27 – 2.12 (m, 1H), 1.77 – 1.66 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.3, 135.5, 134.1, 132.0, 123.3, 95.1, 45.7, 39.9, 32.3, 28.9.

FTIR (NaCl, thin film, cm^{-1}): 1700, 1458, 1395, 1380, 1109, 990, 874, 716.

HRMS (FAB, *m/z*): calc'd for $C_{14}H_{12}NO_2I$ $[M+H]^+$: 353.9991; found: 353.9979.

2-(4-bromocyclohex-3-en-1-yl)isoindoline-1,3-dione (10)



Prepared from 4-(1,3-dioxoisoindolin-2-yl)cyclohex-1-en-1-yl trifluoromethanesulfonate (113 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10 to 25% Et_2O/hexanes) to yield (75.4 mg, 82% yield) as a white solid. The purity was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (82 x 0.96 = 79% yield).

R_f = 0.36 (silica, 30% Et_2O/hexanes, $KMnO_4$).

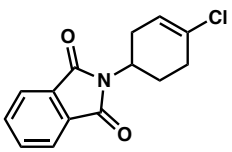
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 – 7.78 (m, 2H), 7.78 – 7.65 (m, 2H), 6.02 (ddt, *J* = 5.2, 2.4, 1.4 Hz, 1H), 4.57 – 4.35 (m, 1H), 3.05 – 2.89 (m, 1H), 2.80 – 2.64 (m, 2H), 2.64 – 2.55 (m, 1H), 2.28 – 2.15 (m, 1H), 1.87 – 1.76 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.3, 134.1, 132.0, 127.0, 123.3, 121.3, 46.0, 35.5, 30.5, 27.9.

FTIR (NaCl, thin film, cm^{-1}): 1695, 1464, 1396, 1111, 992, 919, 875, 717.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{14}H_{12}NO_2Br$ $[M+H]^+$: 306.0130; found: 306.0121.

2-(4-chlorocyclohex-3-en-1-yl)isoindoline-1,3-dione (11)



Prepared from 4-(1,3-dioxoisoindolin-2-yl)cyclohex-1-en-1-yl trifluoromethanesulfonate (113 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10 to 25% Et_2O/hexanes) to yield (68.9 mg, 88% yield) as a white solid.

The purity was determined by ^{1}H NMR to be 95% pure by mass (5% protodetriflation). The yield is adjusted accordingly (88 x 0.95 = 83% yield).

R_f = 0.36 (silica, 30% Et_2O/hexanes, $KMnO_4$).

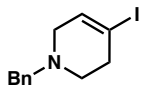
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.87 – 7.78 (m, 2H), 7.76 – 7.67 (m, 2H), 5.80 (dtt, *J* = 5.8, 2.3, 0.7 Hz, 1H), 4.51 – 4.32 (m, 1H), 3.06 – 2.89 (m, 1H), 2.72 (dtd, *J* = 12.3, 11.7, 5.6 Hz, 1H), 2.66 – 2.54 (m, 1H), 2.49 – 2.39 (m, 1H), 2.28 – 2.16 (m, 1H), 1.85 (dddd, *J* = 11.4, 4.7, 3.1, 1.4 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 168.3, 134.2, 132.0, 131.4, 123.3, 122.7, 46.3, 33.0, 29.1, 27.1.

FTIR (NaCl, thin film, cm^{-1}): 1700, 1465, 1378, 1112, 995, 920, 876, 717.

HRMS (FAB, *m/z*): calc'd for $C_{14}H_{12}NO_2Cl$ $[M+H]^+$: 262.0635; found: 262.0636.

1-benzyl-4-iodo-1,2,3,6-tetrahydropyridine (12)



Prepared from 1-benzyl-1,2,3,6-tetrahydropyridin-4-yl trifluoromethanesulfonate 80 mg, 0.25 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield (68 mg, 91% yield) as a light yellow oil.

R_f = 0.31 (silica, 10% Et_2O/hexanes, $KMnO_4$).

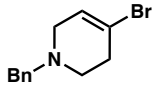
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36 – 7.23 (m, 5H), 6.26 (td, *J* = 3.4, 1.7 Hz, 1H), 3.56 (s, 2H), 3.06 – 2.99 (m, 2H), 2.64 – 2.59 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 138.0, 135.3, 129.2, 128.5, 127.4, 93.2, 62.3, 55.7, 51.7, 39.8.

FTIR (NaCl, thin film, cm^{-1}): 2920, 2800, 2752, 1494, 1454, 1363, 1340, 1054, 960, 729, 698.

HRMS (FAB, *m/z*): calc'd for $C_{12}H_{14}IN$ $[M+H–H_2]^+$: 298.0093; found: 298.0081.

1-benzyl-4-bromo-1,2,3,6-tetrahydropyridine (13)



Prepared from 1-benzyl-1,2,3,6-tetrahydropyridin-4-yl trifluoromethanesulfonate (96 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method

B. The crude residue was purified by column chromatography (silica, 5% to 10 Et_2O/hexanes) to yield (69 mg, 92% yield) as a light yellow oil.

R_f = 0.60 (silica, 20% Et_2O/hexanes, $KMnO_4$).

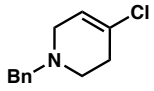
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.39 – 7.21 (m, 5H), 5.97 (tt, *J* = 3.5, 1.6 Hz, 1H), 3.58 (s, 2H), 3.00 (dt, *J* = 3.6, 2.8 Hz, 2H), 2.65 (td, *J* = 5.6, 0.6 Hz, 2H), 2.59 – 2.49 (m, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 138.0, 129.1, 128.4, 127.4, 126.8, 119.9, 62.0, 54.1, 50.9, 35.8.

FTIR (NaCl, thin film, cm^{-1}): 3062, 3027, 2924, 2802, 2756, 1659, 1493, 1454, 1365, 1346, 1056, 995, 965, 822, 732, 698.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{12}H_{14}BrN$ $[M+H]^+$: 252.0388; found: 252.0404.

1-benzyl-4-chloro-1,2,3,6-tetrahydropyridine (14)



Prepared from 1-benzyl-1,2,3,6-tetrahydropyridin-4-yl trifluoromethanesulfonate (96 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 5 to 10% Et_2O/hexanes) to yield (56 mg, 90% yield) as a light yellow oil.

R_f = 0.56 (silica, 20% Et_2O/hexanes, $KMnO_4$).

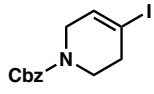
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42 – 7.20 (m, 5H), 5.76 (tt, *J* = 3.5, 1.6 Hz, 1H), 3.60 (s, 2H), 3.03 (dt, *J* = 3.8, 2.8 Hz, 2H), 2.67 (t, *J* = 5.7 Hz, 2H), 2.43 (ttd, *J* = 5.8, 2.7, 1.5 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 138.1, 130.3, 129.2, 128.5, 127.4, 122.5, 62.0, 52.9, 50.2, 33.5.

FTIR (NaCl, thin film, cm^{-1}): 3062, 6027, 2925, 2801, 2759, 1666, 1494, 1454, 1365, 1350, 1059, 998, 972, 824, 735, 698.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{12}H_{14}ClN$ $[M+H]^+$: 208.0893; found: 208.0881.

benzyl 4-iodo-3,6-dihydropyridine-1(2*H*)-carboxylate (15)



Prepared from benzyl 4-(((trifluoromethyl)sulfonyl)oxy)-3,6-dihydropyridine-1(2*H*)-carboxylate (110 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol)

according to Method A. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield (76 mg, 73% yield) as a colorless oil. The purity was determined by ^1H NMR to be 93% pure by mass (7% protodetriflation). The yield is adjusted accordingly (73 x 0.93 = 68% yield).

R_f = 0.25 (silica, 10% EtOAc/hexanes, $KMnO_4$).

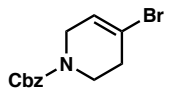
^1H NMR (400 MHz, *d*$_3$-MeCN, 65 °C): δ 7.44 – 7.28 (m, 5H), 6.34 (tt, *J* = 3.5, 1.8 Hz, 1H), 5.13 (s, 2H), 3.97 (q, *J* = 3.0 Hz, 2H), 3.57 (t, *J* = 5.7 Hz, 2H), 2.59 (ttd, *J* = 5.6, 2.7, 1.7 Hz, 2H).

^{13}C NMR (101 MHz, *d*$_3$-MeCN, 65 °C): δ 156.3, 138.4, 135.4, 129.6, 129.1, 128.8, 92.6, 68.0, 47.6, 43.6, 39.8.

FTIR (NaCl, thin film, cm^{-1}): 3032, 2932, 2838, 1704, 1428, 1361, 1335, 1273, 1231, 1108, 1044, 1027, 964, 697.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{13}H_{14}INO_2$ $[M+H]^+$: 344.0148; found: 344.0154.

benzyl 4-bromo-3,6-dihydropyridine-1(2*H*)-carboxylate (16)



Prepared from benzyl 4-(((trifluoromethyl)sulfonyl)oxy)-3,6-dihydropyridine-1(2*H*)-carboxylate (110 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield (86 mg, 93% yield) as a colorless oil. The purity was determined by ^1H NMR to be 95% pure by mass (5% protodetriflation). The yield is adjusted accordingly (93 x 0.95 = 89% yield).

R_f = 0.36 (silica, 30% EtOAc/hexanes, $KMnO_4$).

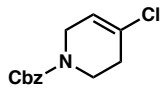
^1H NMR (400 MHz, *d*$_3$-MeCN, 65 °C): δ 7.47 – 7.19 (m, 5H), 6.06 (tt, *J* = 3.4, 1.6 Hz, 1H), 5.14 (s, 2H), 3.96 (q, *J* = 3.0 Hz, 2H), 3.63 (td, *J* = 5.7, 1.5 Hz, 2H), 2.53 (ttd, *J* = 5.7, 2.8, 1.6 Hz, 2H).

^{13}C NMR (101 MHz, *d*$_3$-MeCN, 65 °C): δ 156.2, 138.5, 129.6, 129.1, 128.9, 127.1, 120.2, 68.0, 46.1, 42.9, 35.8.

FTIR (NaCl, thin film, cm^{-1}): 2934, 1698, 1428, 1361, 1336, 1274, 1230, 1111, 1027, 964, 757, 698.

HRMS (FAB, *m/z*): calc'd for $C_{13}H_{14}BrNO_2$ $[M+H]^+$: 296.0286; found: 296.0285.

benzyl 4-chloro-3,6-dihydropyridine-1(2*H*)-carboxylate (17)



Prepared from benzyl 4-(((trifluoromethyl)sulfonyl)oxy)-3,6-dihydropyridine-1(2*H*)-carboxylate (110 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield (70 mg, 92% yield) as a colorless oil. The purity of was determined by ^{1}H NMR to be 95% pure by mass (5% protodetriflation). The yield is adjusted accordingly (92 x 0.95 = 87% yield).

R$_f$ = 0.36 (silica, 30% EtOAc/hexanes, $KMnO_4$).

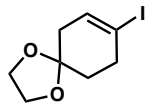
^{1}H NMR (400 MHz, *d$_3$*-MeCN, 65 °C): δ 7.45 – 7.26 (m, 5H), 5.84 (tt, *J* = 3.4, 1.6 Hz, 1H), 5.14 (s, 2H), 3.99 (q, *J* = 2.9 Hz, 2H), 3.64 (t, *J* = 5.8 Hz, 2H), 2.41 (ttd, *J* = 5.7, 2.7, 1.6 Hz, 2H).

^{13}C NMR (101 MHz, *d$_3$*-MeCN, 65 °C): δ 156.2, 138.5, 131.0, 129.7, 129.1, 128.9, 122.9, 68.0, 44.9, 42.4, 33.6.

FTIR (NaCl, thin film, cm^{-1}): 3033, 2940, 1698, 1497, 1428, 1362, 1276, 1233, 1112, 1049, 971, 813, 764, 699.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{13}H_{14}ClNO_2$ $[M+H]^+$: 252.0791; found: 252.0807.

8-iodo-1,4-dioxaspiro[4.5]dec-7-ene (19)



Prepared from 1,4-dioxaspiro[4.5]dec-7-en-8-yl trifluoromethanesulfonate (86.5 mg, 0.3 mmol) and sodium iodide (225 mg, 1.5 mmol) according to Method A with the following modifications: 5 equiv NaI, no cod, and 36 h reaction time. The crude residue was purified by column chromatography (silica, 10% Et_2O/pentane) to yield (68.2 mg, 86% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 95% pure by mass (5% protodetriflation). The yield is adjusted accordingly (86 x 0.95 = 82% yield).

R$_f$ = 0.45 (silica, 10% EtOAc/hexanes, $KMnO_4$).

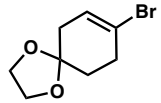
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.18 (td, *J* = 4.0, 2.0 Hz, 1H), 4.06 – 3.88 (m, 4H), 2.70 (ttd, *J* = 6.5, 2.4, 1.7 Hz, 2H), 2.30 (dddd, *J* = 4.0, 3.3, 2.4, 1.2 Hz, 2H), 1.80 (tt, *J* = 6.5, 0.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 134.8, 106.1, 95.0, 64.7, 39.5, 38.7, 33.8.

FTIR (NaCl, thin film, cm^{-1}): 2882, 1651, 1429, 1366, 1252, 1114, 1059, 1022, 914, 860, 650.

HRMS (FAB, *m/z*): calc'd for $C_8H_{11}IO_2$ $[M+H]^+$: 266.9882; found: 266.9885.

8-bromo-1,4-dioxaspiro[4.5]dec-7-ene (20)



Prepared from 1,4-dioxaspiro[4.5]dec-7-en-8-yl trifluoromethanesulfonate (86.5 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% Et_2O/pentane) to yield (62 mg, 94% yield) as a colorless oil.

R_f = 0.41 (silica, 10% EtOAc/hexanes, $KMnO_4$).

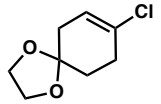
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.91 (tt, *J* = 4.0, 1.6 Hz, 1H), 4.04 – 3.92 (m, 4H), 2.63 (ttd, *J* = 6.5, 2.4, 1.6 Hz, 2H), 2.30 (dddd, *J* = 4.2, 3.3, 2.4, 0.9 Hz, 2H), 1.85 (tt, *J* = 6.6, 0.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 126.2, 121.3, 106.5, 64.7, 37.7, 34.3, 32.8.

FTIR (NaCl, thin film, cm^{-1}): 2883, 1652, 1430, 1368, 1255, 1117, 1060, 1024, 929, 862, 654.

HRMS (EI, *m/z*): calc'd for $C_8H_{11}BrO_2$ $[M+\cdot]^+$: 217.9942; found: 217.9933.

8-chloro-1,4-dioxaspiro[4.5]dec-7-ene (21)



Prepared from 1,4-dioxaspiro[4.5]dec-7-en-8-yl trifluoromethanesulfonate (86.5 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% Et_2O/pentane) to yield (46 mg, 88% yield) as a colorless oil.

R_f = 0.38 (silica, 10% EtOAc/hexanes, $KMnO_4$).

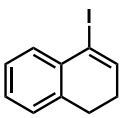
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.68 (tt, *J* = 4.0, 1.6 Hz, 1H), 3.97 (s, 4H), 2.51 (ttd, *J* = 6.5, 2.4, 1.5 Hz, 2H), 2.37 – 2.28 (m, 2H), 1.85 (tt, *J* = 6.6, 0.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 131.4, 121.8, 106.8, 64.7, 36.4, 32.0, 31.9.

FTIR (NaCl, thin film, cm^{-1}): 2933, 2884, 1659, 1433, 1370, 1336, 1251, 1203, 1119, 1062, 1028, 985, 944, 864, 666.

HRMS (TOF-ESI, *m/z*): calc'd for $C_8H_{11}ClO_2$ $[M+H]^+$: 175.0526; found: 175.0521.

4-iodo-1,2-dihydronaphthalene (22)



Prepared from 3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (93.5 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (65.3 mg, 84% yield) as a colorless oil. The purity of was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (84 x 0.98 = 83% yield).

R_f = 0.65 (silica, hexanes, UV).

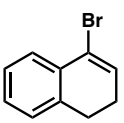
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.43 (dd, *J* = 7.7, 1.3 Hz, 1H), 7.27 – 7.21 (m, 1H), 7.17 (td, *J* = 7.4, 1.4 Hz, 1H), 7.05 – 7.00 (m, 1H), 6.83 (t, *J* = 4.8 Hz, 1H), 2.85 (t, *J* = 8.1 Hz, 2H), 2.36 (ddd, *J* = 9.1, 7.4, 4.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 140.2, 135.9, 134.4, 130.9, 128.4, 127.4, 127.1, 98.1, 27.9, 27.2.

FTIR (NaCl, thin film, cm^{-1}): 3059, 2934, 2882, 2827, 1604, 1476, 1448, 1314, 1276, 938, 805, 756, 727.

HRMS (EI, *m/z*): calc'd for $C_{10}H_9I$ $[M+\cdot]^+$: 255.9749; found: 255.9744.

4-bromo-1,2-dihydronaphthalene (24)



Prepared from 3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (93.5 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (59 mg, 94% yield) as a colorless oil.

R_f = 0.62 (silica, hexanes, UV).

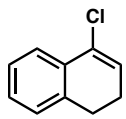
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.56 (dd, *J* = 7.6, 1.4 Hz, 1H), 7.28 – 7.22 (m, 1H), 7.20 (td, *J* = 7.4, 1.5 Hz, 1H), 7.12 – 7.07 (m, 1H), 6.45 (t, *J* = 4.8 Hz, 1H), 2.85 (t, *J* = 8.1 Hz, 2H), 2.37 (ddd, *J* = 9.0, 7.5, 4.8 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 136.4, 133.2, 130.8, 128.4, 127.4, 126.9, 126.6, 121.5, 27.8, 25.6.

FTIR (NaCl, thin film, cm^{-1}): 3059, 2937, 2884, 2831, 1690, 1615, 1479, 1450, 1316, 1169, 948, 809, 758, 730.

HRMS (EI, *m/z*): calc'd for $C_{10}H_9Br$ $[M+\cdot]^+$: 207.9888; found: 207.9876.

4-chloro-1,2-dihydronaphthalene (24)



Prepared from 3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (93.5 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (46 mg, 93% yield) as a colorless oil.

R_f = 0.56 (silica, hexanes, $KMnO_4$).

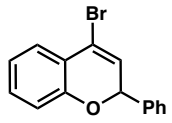
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.59 (dd, *J* = 7.5, 1.5 Hz, 1H), 7.30 – 7.25 (m, 1H), 7.22 (td, *J* = 7.4, 1.6 Hz, 1H), 7.18 – 7.12 (m, 1H), 6.19 (t, *J* = 4.8 Hz, 1H), 2.85 (t, *J* = 8.1 Hz, 2H), 2.41 (ddd, *J* = 9.0, 7.5, 4.8 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 136.4, 132.5, 130.6, 128.3, 127.4, 126.8, 126.1, 124.2, 27.7, 24.3.

FTIR (NaCl, thin film, cm^{-1}): 3063, 2938, 2887, 2832, 1621, 1482, 1451, 1319, 1172, 964, 814, 760, 732.

HRMS (EI, *m/z*): calc'd for $C_{10}H_9Cl$ $[M+\cdot]^+$: 164.0393; found: 164.0382.

4-bromo-2-phenyl-2*H*-chromene (26)



Prepared from 2-phenyl-2*H*-chromen-4-yl trifluoromethanesulfonate (107 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% PhMe-/hexanes) to yield (78.7 mg, 92% yield) as a yellow oil. The purity of was determined by ^{1}H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (92 x 0.97 = 89% yield). *Note: This compound decomposes readily at room temperature.*

R_f = 0.69 (silica, 10% Et_2O/hexanes, $KMnO_4$).

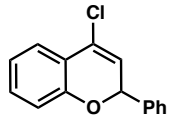
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.46 (ddt, *J* = 7.5, 4.0, 2.1 Hz, 3H), 7.43 – 7.35 (m, 3H), 7.20 (td, *J* = 7.8, 1.7 Hz, 1H), 6.97 (td, *J* = 7.6, 1.2 Hz, 1H), 6.82 (dd, *J* = 8.1, 1.2 Hz, 1H), 6.22 (d, *J* = 3.7 Hz, 1H), 5.92 (d, *J* = 3.7 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 153.4, 139.6, 131.0, 128.91, 128.89, 127.2, 127.1, 126.5, 121.7, 121.1, 118.4, 116.2, 78.7.

FTIR (NaCl, thin film, cm^{-1}): 1645, 1605, 1478, 1464, 1450, 1374, 1223, 1116, 1062, 756, 697.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{11}BrO$ $[M+H-H_2]^+$: 284.9915; found: 284.9917.

4-chloro-2-phenyl-2*H*-chromene (27)



Prepared from 2-phenyl-2*H*-chromen-4-yl trifluoromethanesulfonate (107 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10% PhMe-/hexanes) to yield (72.8 mg, 99% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (99 x 0.96 = 95% yield). *Note: This compound decomposes readily at room temperature.*

R_f = 0.68 (silica, 10% Et_2O/hexanes, $KMnO_4$).

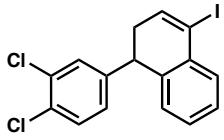
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.50 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.47 – 7.43 (m, 2H), 7.42 – 7.33 (m, 3H), 7.21 (ddd, *J* = 8.1, 7.4, 1.7 Hz, 1H), 5.98 (s, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 153.6, 139.8, 131.0, 128.91, 128.89, 128.3, 127.2, 124.7, 122.0, 121.6, 120.4, 116.2, 78.1.

FTIR (NaCl, thin film, cm^{-1}): 1634, 1605, 1481, 1451, 1328, 1224, 1118, 1064, 981, 914, 852, 754, 697.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{11}ClO$ $[M+\cdot]^+$: 242.0498; found: 242.0518.

4-iodo-1-(3,4-dichlorophenyl)-1,2-dihydronaphthalene (28)



Prepared from 4-(3,4-dichlorophenyl)-3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (127.0 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (96.4 mg, 79% yield) as a white solid. The purity was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (79 x 0.98 = 77% yield).

R_f = 0.44 (silica, hexanes, UV).

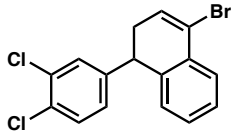
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.54 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.37 (d, *J* = 8.3 Hz, 1H), 7.34 – 7.26 (m, 2H), 7.17 (td, *J* = 7.5, 1.3 Hz, 1H), 6.98 (dd, *J* = 8.3, 2.2 Hz, 1H), 6.78 – 6.71 (m, 2H), 4.17 – 4.09 (m, 1H), 2.70 (ddd, *J* = 16.8, 7.0, 4.9 Hz, 1H), 2.59 (ddd, *J* = 16.8, 9.0, 4.8 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 143.6, 137.9, 136.8, 134.2, 132.7, 131.5, 130.9, 130.6, 130.3, 129.0, 127.9, 127.8, 127.6, 98.0, 43.1, 35.2.

FTIR (NaCl, thin film, cm^{-1}): 3059, 2932, 2876, 2827, 1603, 1561, 1470, 1447, 1396, 1132, 1030, 910, 862, 822, 879, 730.

HRMS (FAB, *m/z*): calc'd for $C_{16}H_{11}ICl_2$ $[M+\cdot]^+$: 399.9283; found: 399.9279.

4-bromo-1-(3,4-dichlorophenyl)-1,2-dihydronaphthalene (29)



Prepared from 4-(3,4-dichlorophenyl)-3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (127.0 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by

column chromatography (silica, pentane) to yield (100.3 mg, 94% yield) as a white solid. The purity was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (94 x 0.98 = 92% yield).

R_f = 0.35 (silica, hexanes, $KMnO_4$).

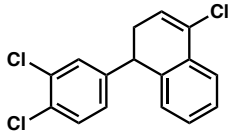
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.67 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.37 (d, *J* = 8.3 Hz, 1H), 7.31 (tdd, *J* = 7.6, 1.4, 0.6 Hz, 1H), 7.29 – 7.27 (m, 1H), 7.20 (td, *J* = 7.5, 1.3 Hz, 1H), 7.00 (ddd, *J* = 8.4, 2.1, 0.5 Hz, 1H), 6.81 (dt, *J* = 7.7, 1.1 Hz, 1H), 6.38 (t, *J* = 4.8 Hz, 1H), 4.17 – 4.10 (m, 1H), 2.72 (ddd, *J* = 16.9, 7.0, 4.9 Hz, 1H), 2.60 (ddd, *J* = 16.9, 9.0, 4.8 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 143.7, 137.4, 132.9, 132.7, 130.9, 130.6, 130.3, 129.0, 128.7, 127.8, 127.75, 127.70, 127.2, 121.5, 43.0, 33.7.

FTIR (NaCl, thin film, cm^{-1}): 3062, 2879, 1618, 1468, 1448, 1397, 1132, 1030, 871, 822, 760.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{16}H_{11}BrCl_2$ $[M+H]^+$: 352.9499; found: 352.9485.

4-chloro-1-(3,4-dichlorophenyl)-1,2-dihydronaphthalene (30)



Prepared from 4-(3,4-dichlorophenyl)-3,4-dihydronaphthalen-1-yl trifluoromethanesulfonate (127.0 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (81 mg, 87% yield) as a white solid.

R_f = 0.55 (silica, hexanes, UV).

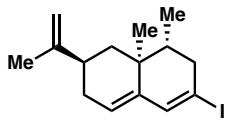
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68 (dd, *J* = 7.8, 1.2 Hz, 1H), 7.37 (d, *J* = 8.3 Hz, 1H), 7.35 – 7.29 (m, 1H), 7.28 (d, *J* = 2.1 Hz, 1H), 7.21 (td, *J* = 7.5, 1.3 Hz, 1H), 7.00 (dd, *J* = 8.3, 2.2 Hz, 1H), 6.84 (dt, *J* = 7.4, 1.1 Hz, 1H), 6.12 (t, *J* = 4.8 Hz, 1H), 4.19 – 4.07 (m, 1H), 2.76 (ddd, *J* = 17.0, 7.1, 4.9 Hz, 1H), 2.63 (ddd, *J* = 16.9, 9.0, 4.7 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 143.8, 137.4, 132.7, 132.3, 130.9, 130.8, 130.6, 130.4, 129.0, 127.8, 127.7, 127.6, 124.8, 124.0, 43.0, 32.5.

FTIR (NaCl, thin film, cm^{-1}): 3063, 2880, 1625, 1559, 1468, 1449, 1398, 1133, 1030, 980, 878, 814, 762, 735.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{16}H_{11}Cl_3$ $[M+H]^+$: 309.0005; found: 309.0005.

(2*R*,8*R*,8a*S*)-6-iodo-8,8a-dimethyl-2-(prop-1-en-2-yl)-1,2,3,7,8,8a-hexahydronaphthalene (31)



Prepared from (4*R*,4a*S*,6*R*)-4,4a-dimethyl-6-(prop-1-en-2-yl)-3,4,4a,5,6,7-hexahydronaphthalen-2-yl 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate (**S5**, 150 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 3. The crude residue was purified by column chromatography (silica, pentane) to yield (54 mg, 54% yield) as a colorless oil. *Note: This compound decomposes readily at room temperature.*

$\mathbf{R}_f$ = 0.63 (silica, hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –155° (c = 1.0, $CHCl_3$).

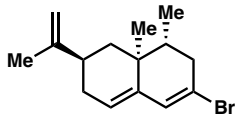
^{1}H NMR (500 MHz, $CDCl_3$): δ 6.58 (d, *J* = 2.4 Hz, 1H), 5.41 (dd, *J* = 5.4, 2.8 Hz, 1H), 4.80 – 4.70 (m, 2H), 2.54 (dd, *J* = 18.4, 5.2 Hz, 1H), 2.40 (dddd, *J* = 16.9, 8.5, 4.3, 2.4 Hz, 2H), 2.23 (dddd, *J* = 20.0, 6.8, 5.1, 2.3 Hz, 1H), 2.01 – 1.85 (m, 1H), 1.79 – 1.65 (m, 5H), 1.20 – 1.11 (m, 1H), 0.92 (d, *J* = 0.7 Hz, 3H), 0.86 (d, *J* = 6.9 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 150.0, 142.8, 139.1, 124.4, 109.0, 95.1, 46.1, 41.5, 40.0, 37.1, 35.5, 31.1, 20.8, 17.6, 14.2.

FTIR (NaCl, thin film, cm^{-1}): 3079, 2967, 2912, 1644, 1615, 1441, 1372, 1157, 888, 783.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{21}I$ $[M+H–H_2]^+$: 327.0610; found: 327.0598.

(2*R*,8*R*,8a*S*)-6-bromo-8,8a-dimethyl-2-(prop-1-en-2-yl)-1,2,3,7,8,8a-hexahydronaphthalene (32)



Prepared from (4*R*,4a*S*,6*R*)-4,4a-dimethyl-6-(prop-1-en-2-yl)-3,4,4a,5,6,7-hexahydronaphthalen-2-yl trifluoromethanesulfonate (105.1 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (75 mg, 89% yield) as a colorless oil which solidified in the freezer to give a white solid. The purity was determined by ^{1}H NMR to be 95% pure by mass (5% protodetriflation). The yield is adjusted accordingly (89 x 0.95 = 84% yield). *Note: This compound decomposes readily at room temperature.*

R$_f$ = 0.57 (silica, hexanes, KMnO$_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –172° (c = 1.0, CHCl$_3$).

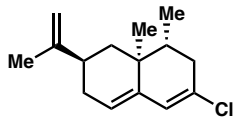
^{1}H NMR (400 MHz, CDCl$_3$): δ 6.30 (d, *J* = 2.3 Hz, 1H), 5.45 (dd, *J* = 5.3, 2.8 Hz, 1H), 4.85 – 4.66 (m, 2H), 2.50 – 2.28 (m, 3H), 2.22 (dt, *J* = 18.6, 5.4 Hz, 1H), 1.99 – 1.85 (m, 1H), 1.75 (s, 3H), 1.74 – 1.63 (m, 2H), 1.16 (t, *J* = 12.7 Hz, 1H), 0.92 (s, 3H), 0.90 (d, *J* = 6.9 Hz, 3H).

^{13}C NMR (101 MHz, CDCl$_3$): δ 150.0, 141.8, 131.0, 124.3, 121.0, 109.0, 41.9, 40.8, 40.0, 37.2, 35.6, 31.2, 20.8, 17.6, 14.4.

FTIR (NaCl, thin film, cm^{-1}): 2959, 2914, 1643, 1620, 1442, 1376, 1349, 1154, 1005, 902, 888, 792, 632.

HRMS (FAB, *m/z*): calc'd for $C_{15}H_{21}Br$ $[M+H-H_2]^+$: 279.0748; found: 279.0744.

(2*R*,8*R*,8a*S*)-6-chloro-8,8a-dimethyl-2-(prop-1-en-2-yl)-1,2,3,7,8,8a-hexahydronaphthalene (33)



Prepared from (4*R*,4a*S*,6*R*)-4,4a-dimethyl-6-(prop-1-en-2-yl)-3,4,4a,5,6,7-hexahydronaphthalen-2-yl trifluoromethanesulfonate (105.1 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (62 mg, 88% yield) as a colorless oil. *Note: This compound decomposes readily at room temperature.*

R$_f$ = 0.63 (silica, hexanes, KMnO$_4$).

$[\boldsymbol{a}]_{\boldsymbol{D}}^{\mathbf{25}}$ = –165° (c = 1.0, $CHCl_3$).

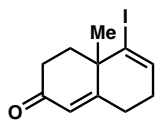
^{1}H NMR (500 MHz, $CDCl_3$): δ 6.09 (dt, *J* = 1.9, 0.9 Hz, 1H), 5.48 – 5.40 (m, 1H), 4.75 (p, *J* = 1.1 Hz, 2H), 2.50 – 2.34 (m, 1H), 2.30 – 2.18 (m, 3H), 2.04 – 1.88 (m, 1H), 1.75 (t, *J* = 1.2 Hz, 3H), 1.74 – 1.70 (m, 1H), 1.70 – 1.64 (m, 1H), 1.21 – 1.12 (m, 1H), 0.93 – 0.89 (m, 6H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 150.0, 141.0, 130.5, 126.9, 124.0, 109.0, 40.0, 39.9, 39.5, 37.2, 35.7, 31.3, 20.8, 17.6, 14.5.

FTIR (NaCl, thin film, cm^{-1}): 3080, 2967, 2912, 1644, 1618, 1442, 1373, 1155, 1014, 888, 824, 635.

HRMS (EI, *m/z*): calc'd for $C_{15}H_{21}Cl$ $[M+\cdot]^+$: 236.1332; found: 236.1356.

5-iodo-4a-methyl-4,4a,7,8-tetrahydronaphthalen-2(3*H*)-one (34)



Prepared from 8a-methyl-6-oxo-3,4,6,7,8,8a-hexahydronaphthalen-1-yl 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulfonate (**S6**, 138 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 3. The crude residue was purified by column chromatography (silica, 5-10% Et_2O/hexanes) to yield (46 mg, 53% yield) as a colorless oil. *Note: This compound decomposes readily at room temperature.*

R_f = 0.24 (silica, 10% Et_2O/hexanes, $KMnO_4$).

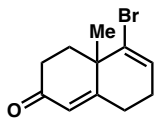
^{1}H NMR (500 MHz, $CDCl_3$): δ 6.68 (dt, *J* = 2.6, 0.8 Hz, 1H), 5.66 – 5.58 (m, 1H), 2.76 (ddd, *J* = 15.5, 7.3, 5.9 Hz, 1H), 2.72 (s, 2H), 2.63 – 2.53 (m, 1H), 2.49 – 2.40 (m, 1H), 2.36 (ddd, *J* = 15.5, 7.3, 6.7 Hz, 1H), 1.87 – 1.80 (m, 1H), 1.71 (dddd, *J* = 13.5, 11.5, 6.5, 0.8 Hz, 1H), 1.22 (d, *J* = 0.6 Hz, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 214.3, 140.3, 137.7, 123.7, 96.8, 44.3, 36.6, 35.4, 31.3, 24.2, 22.8.

FTIR (NaCl, thin film, cm^{-1}): 2926, 1711, 1443, 1322, 1047, 884.

HRMS (FAB, *m/z*): calc'd for $C_{11}H_{13}OI$ $[M+\cdot]^+$: 288.0011 found: 287.9997.

5-bromo-4a-methyl-4,4a,7,8-tetrahydronaphthalen-2(3*H*)-one (35)



Prepared from 8a-methyl-6-oxo-3,4,6,7,8,8a-hexahydronaphthalen-1-yl trifluoromethanesulfonate (93.1 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 5% Et_2O/hexanes) to yield (69 mg, 95% yield) as a colorless oil. *Note: This compound decomposes readily at room temperature.*

R_f = 0.24 (silica, 10% Et_2O/hexanes, $KMnO_4$).

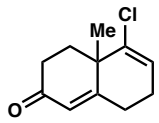
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.41 (td, *J* = 1.6, 0.8 Hz, 1H), 5.67 (t, *J* = 4.4 Hz, 1H), 2.77 (dddd, *J* = 15.4, 7.4, 5.8, 1.1 Hz, 1H), 2.73 – 2.41 (m, 4H), 2.41 – 2.32 (m, 1H), 1.95 (ddt, *J* = 13.4, 5.5, 1.5 Hz, 1H), 1.76 – 1.62 (m, 1H), 1.26 – 1.22 (m, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 214.2, 139.4, 129.7, 123.7, 122.9, 44.5, 35.4, 32.5, 30.5, 24.4, 22.8.

FTIR (NaCl, thin film, cm^{-1}): 2930, 1713, 1611, 1445, 1348, 1048, 884, 750.

HRMS (FAB, *m/z*): calc'd for $C_{11}H_{13}OBr$ $[M+\cdot]^+$: 240.0150; found: 240.0153.

5-chloro-4a-methyl-4,4a,7,8-tetrahydronaphthalen-2(3*H*)-one (36)



Prepared from 8a-methyl-6-oxo-3,4,6,7,8,8a-hexahydronaphthalen-1-yl trifluoromethanesulfonate (93.1 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 5% Et_2O/hexanes) to yield (55 mg, 93% yield) as a colorless oil. *Note: This compound decomposes readily at room temperature.*

R_f = 0.13 (silica, 10% EtOAc/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.19 (dd, *J* = 2.4, 0.8 Hz, 1H), 5.69 – 5.61 (m, 1H), 2.77 (ddd, *J* = 15.4, 7.2, 5.9 Hz, 1H), 2.68 – 2.53 (m, 2H), 2.53 – 2.32 (m, 3H), 2.03 – 1.94 (m, 1H), 1.67 (dddd, *J* = 13.6, 12.1, 5.9, 0.8 Hz, 1H), 1.22 (d, *J* = 0.7 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 214.2, 138.8, 132.4, 125.7, 123.4, 44.6, 35.5, 30.1, 29.8, 24.5, 22.8.

FTIR (NaCl, thin film, cm^{-1}): 3549, 2938, 1714, 1682, 1652, 1446, 1424, 1253, 1155, 1080, 916, 733.

HRMS (EI, *m/z*): calc'd for $C_{11}H_{13}OCl$ $[M+\cdot]^+$: 196.0655; found: 196.0663.

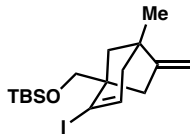
***tert*-butyl(((1*r*,5*r*)-2-iodo-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-1-yl)methoxy)-dimethylsilane (37)**

Prepared from (1*r*,5*r*)-1-(((*tert*-butyldimethylsilyl)oxy)methyl)-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-2-yl trifluoromethanesulfonate (128 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (111 mg, 91% yield) as a colorless oil.

R$_f$ = 0.60 (silica, hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.23 (dd, *J* = 4.8, 2.5 Hz, 1H), 4.93 – 4.89 (m, 1H), 4.88 (dd, *J* = 2.9, 1.8 Hz, 1H), 3.70 (d, *J* = 9.9 Hz, 1H), 3.49 (d, *J* = 9.9 Hz, 1H), 2.45 – 2.21 (m, 3H), 1.97 – 1.75 (m, 3H), 1.18 (s, 3H), 0.91 (s, 9H), 0.09 (s, 3H), 0.07 (s, 3H).

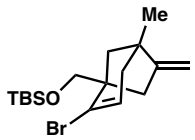
^{13}C NMR (101 MHz, $CDCl_3$): δ 158.7, 137.8, 107.3, 106.1, 71.1, 50.0, 49.0, 46.8, 43.4, 43.3, 26.1, 24.9, 18.5, -5.1, -5.3.



FTIR (NaCl, thin film, cm^{-1}): 2954, 2929, 2857, 1655, 1471, 1464, 1251, 1156, 1097, 1007, 879, 851, 838, 808, 776.

HRMS (FAB, *m/z*): calc'd for $C_{17}H_{29}OISi$ $[M+H-H_2]^+$: 403.0955; found: 403.0969.

***tert*-butyl(((1*r*,5*r*)-2-bromo-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-1-yl)methoxy)-dimethylsilane (38)**



Prepared from (1*r*,5*r*)-1-(((*tert*-butyldimethylsilyl)oxy)methyl)-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-2-yl trifluoromethanesulfonate (128 mg, 0.3 mmol) and lithium bromide (39.0 mg, 0.15 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (98 mg, 91% yield) as a colorless oil.

R_f = 0.58 (silica, hexanes, $KMnO_4$).

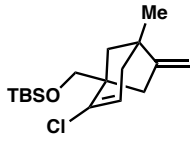
^{1}H NMR (500 MHz, $CDCl_3$): δ 5.86 (dd, *J* = 4.9, 2.5 Hz, 1H), 4.91 (t, *J* = 2.1 Hz, 1H), 4.89 (t, *J* = 2.4 Hz, 1H), 3.82 (dd, *J* = 9.9, 0.9 Hz, 1H), 3.57 (d, *J* = 9.9 Hz, 1H), 2.47 (d, *J* = 15.2 Hz, 1H), 2.39 (dt, *J* = 15.7, 2.8 Hz, 1H), 2.24 (dd, *J* = 16.8, 2.6 Hz, 1H), 1.90 (dd, *J* = 16.9, 4.9 Hz, 1H), 1.82 (s, 2H), 1.19 (s, 3H), 0.90 (s, 9H), 0.07 (s, 3H), 0.06 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 158.8, 129.8, 128.6, 106.1, 67.2, 50.0, 47.3, 46.8, 43.7, 43.2, 26.1, 24.8, 18.5, -5.26, -5.33.

FTIR (NaCl, thin film, cm^{-1}): 2954, 2857, 1652, 1463, 1251, 1097, 1010, 880, 839, 811, 775

HRMS (FAB, *m/z*): calc'd for $C_{17}H_{29}OBrSi$ $[M+H-H_2]^+$: 357.1072; found: 357.1085.

tert-butyl(((1_r_,5_r_)-2-chloro-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-1-yl)methoxy)-dimethylsilane (39)



Prepared from (1*r*,5*r*)-1-(((*tert*-butyldimethylsilyl)oxy)methyl)-5-methyl-6-methylenebicyclo[3.2.1]oct-2-en-2-yl trifluoromethanesulfonate (128 mg, 0.3 mmol) and lithium chloride (6.4 mg, 0.15 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (78 mg, 83% yield) as a colorless oil.

R_f = 0.56 (silica, hexanes, $KMnO_4$).

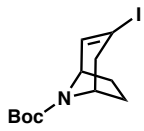
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.61 (dd, *J* = 4.8, 2.5 Hz, 1H), 4.90 (dd, *J* = 2.4, 1.7 Hz, 1H), 4.89 – 4.87 (m, 1H), 3.88 (d, *J* = 9.9 Hz, 1H), 3.59 (d, *J* = 9.9 Hz, 1H), 2.50 (dq, *J* = 15.7, 1.9 Hz, 1H), 2.46 – 2.38 (m, 1H), 2.26 (dd, *J* = 16.9, 2.5 Hz, 1H), 1.98 – 1.89 (m, 1H), 1.83 – 1.75 (m, 2H), 1.21 (s, 3H), 0.90 (s, 9H), 0.06 (s, 3H), 0.06 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 158.9, 138.3, 124.0, 106.0, 65.4, 49.5, 47.2, 45.2, 43.9, 43.2, 26.1, 24.8, 18.5, -5.33, -5.34.

FTIR (NaCl, thin film, cm^{-1}): 2954, 2858, 1656, 1471, 1252, 1098, 880, 838, 812, 776

HRMS (TOF-ESI, *m/z*): calc'd for $C_{17}H_{29}OClSi$ $[M+H]^+$: 313.1754; found: 313.1732.

***tert*-butyl (1*r*,5*s*)-3-iodo-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (40)**



Prepared from *tert*-butyl (1*r*,5*s*)-3-(((perfluorobutyl)sulfonyl)oxy)-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (**S7**, 152 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 3. The crude residue was purified by column chromatography (silica, 10 to 6% acetone/hexanes) to yield (53 mg, 53% yield) as a colorless oil.

$\mathbf{R_f}$ = 0.55 (silica, 30% Et_2O/hexanes, $KMnO_4$).

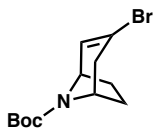
^{1}H NMR (400 MHz, d_3-MeCN, 65 °C): δ 6.70 – 6.65 (m, 1H), 4.23 (t, *J* = 5.6 Hz, 1H), 4.17 – 4.11 (m, 1H), 3.16 – 3.06 (m, 1H), 2.31 (dt, *J* = 17.5, 1.4 Hz, 1H), 2.26 – 2.12 (m, 1H), 1.98 – 1.81 (m, 2H), 1.76 (ddt, *J* = 15.6, 9.8, 3.8 Hz, 1H), 1.44 (d, *J* = 0.6 Hz, 9H).

^{13}C NMR (101 MHz, d_3-MeCN, 65 °C): δ 6.70 – 6.65 (m, 1H), 4.23 (t, *J* = 5.6 Hz, 1H), 4.17 – 4.11 (m, 1H), 3.16 – 3.06 (m, 1H), 2.31 (dt, *J* = 17.5, 1.4 Hz, 1H), 2.26 – 2.12 (m, 1H), 1.98 – 1.81 (m, 2H), 1.76 (ddt, *J* = 15.6, 9.8, 3.8 Hz, 1H), 1.44 (d, *J* = 0.6 Hz, 9H).

FTIR (NaCl, thin film, cm^{-1}): 2975, 1698, 1392, 1347, 1312, 1172, 1103, 1101, 973.

HRMS (FAB, *m/z*): calc'd for $C_{12}H_{18}INO_2$ $[M+H]^+$: 336.0461; found: 336.0454.

***tert*-butyl (1*r*,5*s*)-3-bromo-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (41)**



Prepared from *tert*-butyl (1*r*,5*s*)-3-(((trifluoromethyl)sulfonyl)oxy)-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (107 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10 to 20% Et_2O/hexanes) to yield (85 mg, 98% yield) as a colorless oil. The purity of was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (98 x 0.96 = 94% yield).

Prepared from *tert*-butyl (1*r*,5*s*)-3-(((trifluoromethyl)sulfonyl)oxy)-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (357 mg, 1.0 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B, procedure 2. The crude residue was purified by column chromatography (silica, 10 to 20% Et_2O/Hexanes) to yield (283 mg, 98% yield) as a pale yellow oil. The purity of was determined by ^1H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (98*0.97 =95% yield).

R_f = 0.55 (silica, 30% Et_2O/hexanes, $KMnO_4$).

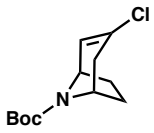
^1H NMR (400 MHz, d_3-MeCN, 65 °C): δ 6.44 (dt, *J* = 5.5, 1.7 Hz, 1H), 4.38 (t, *J* = 5.5 Hz, 1H), 4.35 – 4.25 (m, 1H), 3.11 (ddt, *J* = 17.5, 4.2, 1.9 Hz, 1H), 2.32 – 2.18 (m, 2H), 2.04 – 1.90 (m, 2H), 1.85 – 1.75 (m, 1H), 1.50 (s, 9H).

^{13}C NMR (101 MHz, d_3-MeCN, 65 °C): δ 155.0, 135.7, 121.0, 80.5, 56.2, 54.8, 44.9, 35.0, 30.5, 28.9.

FTIR (NaCl, thin film, cm^{-1}): 2976, 1698, 1392, 1367, 1350, 1320, 1171, 1103, 1107, 975.

HRMS (FAB, *m/z*): calc'd for $C_{12}H_{18}BrNO_2$ $[M+H]^+$: 288.0599; found: 288.0593.

***tert*-butyl (1r,5*s*)-3-chloro-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (42)**



Prepared from *tert*-butyl (1*r*,5*s*)-3-(((trifluoromethyl)sulfonyl)oxy)-8-azabicyclo[3.2.1]oct-2-ene-8-carboxylate (107 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, 10 to 20% Et_2O/hexanes) to yield (72 mg, 98% yield) as a colorless oil. The purity was determined by ^1H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (98 x 0.97 = 95% yield).

R_f = 0.55 (silica, 30% Et_2O/hexanes, $KMnO_4$).

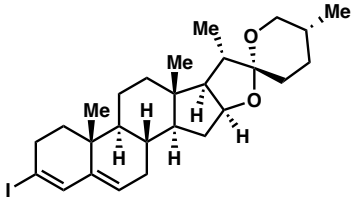
^1H NMR (400 MHz, d_3-MeCN, 65 °C): δ 6.20 (ddd, *J* = 5.5, 2.0, 1.4 Hz, 1H), 4.43 – 4.38 (m, 1H), 4.35 (ddq, *J* = 7.2, 4.8, 1.2 Hz, 1H), 2.99 (ddd, *J* = 17.2, 4.4, 2.2 Hz, 1H), 2.28 – 2.16 (m, 1H), 2.13 (dt, *J* = 17.3, 1.3 Hz, 1H), 2.01 – 1.93 (m, 2H), 1.82 – 1.72 (m, 1H), 1.49 (s, 9H).

^{13}C NMR (101 MHz, d_3-MeCN, 65 °C): δ 155.0, 131.4, 80.5, 55.0, 54.0, 42.6, 35.2, 30.5, 28.9. (*Note: one carbon under solvent*).

FTIR (NaCl, thin film, cm^{-1}): 2976, 1694, 1638, 1392, 1323, 1256, 1168, 1103, 1015, 978, 888, 874, 775, 724.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{12}H_{18}ClNO_2$ $[M+H]^+$: 244.1104; found: 244.1098.

(5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-4-iodo-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]furan-10,2'-pyran] (43)



Prepared from (5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,12a,-12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]furan-10,2'-pyran]-4-yl trifluoromethanesulfonate (109 mg, 0.2 mmol) and sodium iodide (150 mg, 1.0 mmol) according to Method A with the exception that the reaction was run at 0.125 M for 36 h and no cod was used. The crude residue was purified by column chromatography (silica, 2 to 6% Et_2O/hexanes) to yield (89 mg, 85% yield) as a white solid.

R_f = 0.56 (silica, 10% Et_2O/hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –187° (c = 1.0, $CHCl_3$).

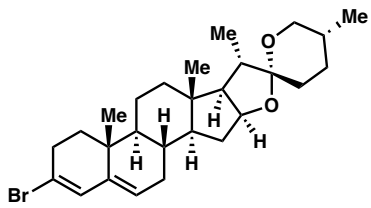
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.26 (d, *J* = 2.3 Hz, 1H), 5.39 (dd, *J* = 5.1, 2.9 Hz, 1H), 4.41 (ddd, *J* = 8.6, 7.5, 6.3 Hz, 1H), 3.47 (ddd, *J* = 10.9, 4.6, 2.0 Hz, 1H), 3.36 (t, *J* = 10.8 Hz, 1H), 2.67 – 2.53 (m, 1H), 2.46 (ddd, *J* = 18.4, 5.9, 1.6 Hz, 1H), 2.17 (dt, *J* = 18.7, 5.3 Hz, 1H), 1.98 (ddd, *J* = 11.8, 7.5, 5.4 Hz, 1H), 1.91 – 1.10 (m, 17H), 1.05 – 0.92 (m, 7H), 0.84 – 0.74 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 142.4, 139.4, 124.5, 109.4, 95.0, 80.9, 67.0, 62.2, 56.7, 48.1, 41.7, 40.5, 39.8, 37.4, 36.4, 34.5, 31.88, 31.85, 31.5, 31.3, 30.4, 28.9, 20.9, 19.1, 17.3, 16.5, 14.7.

FTIR (NaCl, thin film, cm^{-1}): 2949, 1454, 1376, 1241, 1172, 1052, 980, 898, 755.

HRMS (FAB, *m/z*): calc'd for $C_{27}H_{39}IO_2$ $[M+H]^+$: 523.2073; found: 523.2059.

(5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-4-bromo-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]furan-10,2'-pyran] (44)



Prepared from (5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,-12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]-furan-10,2'-pyran]-4-yl trifluoromethanesulfonate (109 mg, 0.2 mmol) and lithium bromide (26.1 mg, 0.3 mmol) according to Method B with the exception that DMAP (0.02 mmol, 2.5 mg) was used in place of cod and the reaction was run at 0.125 M. The crude residue was purified by column chromatography (silica, 2 to 6% Et_2O/hexanes) to yield (90 mg, 93% yield) as a white solid.

R_f = 0.56 (silica, 10% Et_2O/hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –176° (c = 1.0, $CHCl_3$).

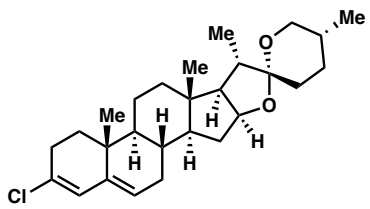
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.27 (d, *J* = 2.3 Hz, 1H), 5.39 (dd, *J* = 5.0, 2.9 Hz, 1H), 4.41 (ddd, *J* = 8.6, 7.5, 6.4 Hz, 1H), 3.48 (ddd, *J* = 10.8, 4.3, 2.1 Hz, 1H), 3.38 (t, *J* = 10.9 Hz, 1H), 2.61 (td, *J* = 14.7, 11.9, 5.1 Hz, 1H), 2.47 (dd, *J* = 18.2, 5.6 Hz, 1H), 2.18 (dt, *J* = 18.8, 5.3 Hz, 1H), 2.00 (ddd, *J* = 11.8, 7.5, 5.4 Hz, 1H), 1.88 (p, *J* = 6.9 Hz, 1H), 1.84 – 1.11 (m, 17H), 1.06 – 0.95 (m, 7H), 0.81 (s, 3H), 0.80 (d, *J* = 6.3 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 141.3, 131.2, 124.4, 121.0, 109.4, 80.9, 67.0, 62.2, 56.7, 48.0, 41.7, 40.5, 39.8, 35.6, 34.6, 33.2, 32.0, 31.9, 31.5, 31.3, 30.4, 28.9, 21.0, 19.1, 17.3, 16.5, 14.7.

FTIR (NaCl, thin film, cm^{-1}): 2949, 1616, 1455, 1377, 1241, 1173, 1051, 980, 899, 734.

HRMS (FAB, *m/z*): calc'd for $C_{27}H_{39}BrO_2$ $[M+H]^+$: 475.2035; found: 475.2049.

(5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-4-chloro-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]furan-10,2'-pyran] (45)



Prepared from (5'*R*,6a*R*,6b*S*,8a*S*,8b*R*,9*S*,10*R*,11a*S*,12a*S*,12b*S*)-5',6a,8a,9-tetramethyl-1,3',4',5,5',6,6a,6b,6',7,8,8a,8b,9,11a,12,-12a,12b-octadecahydrospiro[naphtho[2',1':4,5]indeno[2,1-*b*]-furan-10,2'-pyran]-4-yl trifluoromethanesulfonate (109 mg, 0.2 mmol) and lithium chloride (12.7 mg, 0.3 mmol) according to Method B with the exception that DMAP (0.02 mmol, 2.5 mg) was used in place of cod and the reaction was run at 0.125 M. The crude residue was purified by column chromatography (silica, 2 to 6% Et_2O/hexanes) to yield (73 mg, 83% yield) as a white solid.

R_f = 0.57 (silica, 10% Et_2O/hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –183° (c = 1.0, $CHCl_3$).

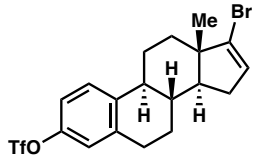
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.06 (d, *J* = 2.3 Hz, 1H), 5.39 (dd, *J* = 5.0, 2.9 Hz, 1H), 4.42 (ddd, *J* = 8.6, 7.5, 6.4 Hz, 1H), 3.48 (ddd, *J* = 10.8, 4.4, 2.0 Hz, 1H), 3.38 (t, *J* = 10.9 Hz, 1H), 2.50 (td, *J* = 14.8, 12.0, 5.3 Hz, 1H), 2.39 – 2.27 (m, 1H), 2.20 (dt, *J* = 18.7, 5.3 Hz, 1H), 2.00 (ddd, *J* = 11.8, 7.5, 5.4 Hz, 1H), 1.93 – 1.51 (m, 11H), 1.52 – 1.37 (m, 2H), 1.38 – 1.28 (m, 2H), 1.25 – 1.12 (m, 2H), 1.07 – 0.95 (m, 7H), 0.82 (s, 3H), 0.80 (d, *J* = 6.4 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 140.7, 130.4, 127.1, 124.1, 109.4, 80.9, 67.0, 62.2, 56.7, 48.0, 41.7, 40.5, 39.8, 34.9, 34.8, 32.1, 31.9, 31.5, 31.4, 30.8, 30.4, 28.9, 21.1, 19.1, 17.3, 16.5, 14.7.

FTIR (NaCl, thin film, cm^{-1}): 2950, 2906, 1622, 1450, 1380, 1350, 1240, 1170, 1070, 1050, 981, 900, 868, 734.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{27}H_{39}ClO_2$ $[M+H]^+$: 431.2717; found: 431.2716.

(8*R*,9*S*,13*S*,14*S*)-17-bromo-13-methyl-7,8,9,11,12,13,14,15-octahydro-6*H*-cyclopenta[*a*]phenanthren-3-yl trifluoromethanesulfonate (46)



Prepared from (8*R*,9*S*,13*S*,14*S*)-13-methyl-7,8,9,11,12,13,14,15-octahydro-6*H*-cyclopenta[*a*]phenanthrene-3,17-diyl bis(trifluoromethane-sulfonate) (160.3 mg, 0.2 mmol) and lithium bromide (26 mg, 0.3 mmol) according to Method B with the exception that DMAP (0.02 mmol, 2.5 mg) was used in place of

cod. The crude residue was purified by column chromatography (silica, 5% to 15% PhMe/hexanes) to yield (91 mg, 95% yield) as a colorless, tacky oil.

R_f = 0.38 (silica, 10% PhMe/hexanes, $KMnO_4$).

$[\boldsymbol{a}]_D^{25}$ = +39° (c = 1.0, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33 (dd, *J* = 8.7, 1.1 Hz, 1H), 7.03 (dd, *J* = 8.6, 2.8 Hz, 1H), 6.98 (d, *J* = 2.7 Hz, 1H), 5.88 (dd, *J* = 3.3, 1.7 Hz, 1H), 2.98 – 2.88 (m, 2H), 2.44 – 2.36 (m, 1H), 2.36 – 2.29 (m, 1H), 2.25 (ddd, *J* = 14.8, 6.3, 3.3 Hz, 1H), 2.02 (ddd, *J* = 14.8, 11.1, 1.8 Hz, 1H), 1.98 – 1.92 (m, 1H), 1.89 (ddd, *J* = 12.3, 3.7, 2.1 Hz, 1H), 1.73 (td, *J* = 11.2, 6.2 Hz, 1H), 1.68 – 1.40 (m, 4H), 0.87 (s, 3H).

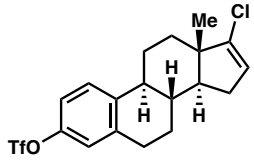
^{13}C NMR (101 MHz, $CDCl_3$): δ 147.7, 140.8, 139.5, 135.6, 129.1, 127.0, 121.3, 118.9 (q, $J_{C\text{-}F}$ = 320.7 Hz), 118.3, 54.9, 48.9, 44.4, 37.1, 34.6, 31.7, 29.5, 27.0, 26.2, 15.3.

^{19}F NMR (282 MHz, $CDCl_3$): δ -72.9.

FTIR (NaCl, thin film, cm^{-1}): 2932, 1592, 1490, 1422, 1247, 1210, 1142, 996, 919, 882, 846.

HRMS (FAB, *m/z*): calc'd for $C_{19}H_{20}BrF_3O_3S$ $[M+H-H_2]^+$: 465.0170; found: 465.0165.

(8*R*,9*S*,13*S*,14*S*)-17-chloro-13-methyl-7,8,9,11,12,13,14,15-octahydro-6*H*-cyclopenta[*a*]phenanthren-3-yl trifluoromethanesulfonate (47)



Prepared from (8*R*,9*S*,13*S*,14*S*)-13-methyl-7,8,9,11,12,13,14,15-octahydro-6*H*-cyclopenta[*a*]phenanthrene-3,17-diyl bis(trifluoromethanesulfonate) (160.3 mg, 0.2 mmol) and lithium chloride (12.7 mg, 0.3 mmol) according to Method B with the exception that DMAP (0.02 mmol, 2.5 mg) was used in place of cod. The crude residue was purified by column chromatography (silica, 1.5% EtOAc/hexanes) to yield (78 mg, 90% yield) as a colorless, tacky oil.

R_f = 0.67 (silica, 10% EtOAc/hexanes, $KMnO_4$).

$[\boldsymbol{a}]_D^{25}$ = +67° (c = 1.0, $CHCl_3$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33 (dd, *J* = 8.7, 1.1 Hz, 1H), 7.03 (dd, *J* = 8.7, 2.8 Hz, 1H), 6.98 (d, *J* = 2.7 Hz, 1H), 5.67 (dd, *J* = 3.3, 1.7 Hz, 1H), 2.93 (dd, *J* = 9.1, 4.3 Hz, 2H), 2.44 – 2.21 (m, 3H), 2.04 (ddd, *J* = 14.8, 11.0, 1.7 Hz, 1H), 1.95 (ddq, *J* = 11.7, 6.3, 3.5, 2.6 Hz, 2H), 1.72 (td, *J* = 11.2, 6.3 Hz, 1H), 1.68 – 1.40 (m, 4H), 0.91 (s, 3H).

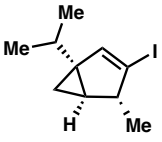
^{13}C NMR (101 MHz, $CDCl_3$): δ 147.7, 144.7, 140.9, 139.5, 127.0, 124.7, 121.3, 118.9 (q, $J_{C\text{-}F}$ = 320.7 Hz), 118.3, 55.1, 47.9, 44.5, 36.9, 33.8, 30.5, 29.5, 26.9, 26.1, 15.2.

^{19}F NMR (282 MHz, $CDCl_3$): δ -72.9.

FTIR (NaCl, thin film, cm^{-1}): 2934, 2859, 1598, 1490, 1417, 1248, 1211, 1142, 1007, 919, 851, 822, 701, 608.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{19}H_{20}ClF_3O_3S$ $[M+H]^+$: 421.0852; found: 421.0845.

(1*S*,4*R*,5*R*)-3-iodo-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-ene (49)



Prepared from (1*S*,4*R*,5*R*)-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-en-3-yl trifluoromethanesulfonate (85.3 mg, 0.3 mmol) and sodium iodide (225 mg, 1.5 mmol) according to Method A with the exception that the reaction was run for 36 h and no cod was used. The crude residue was purified by column chromatography (silica, pentane) to yield (49.5 mg, 63% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (63 x 0.98 = 62% yield).

R_f = 0.88 (silica, hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –6° (c = 1.0, $CHCl_3$).

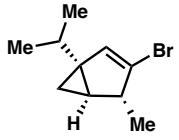
^{1}H NMR (500 MHz, $CDCl_3$): δ 6.18 (dd, *J* = 1.7, 0.9 Hz, 1H), 2.59 – 2.47 (m, 1H), 1.41 (dt, *J* = 13.6, 6.8 Hz, 1H), 1.17 (ddt, *J* = 7.8, 4.1, 0.8 Hz, 1H), 1.06 (d, *J* = 7.1 Hz, 3H), 1.00 (d, *J* = 6.9 Hz, 3H), 0.89 (d, *J* = 6.8 Hz, 3H), 0.84 – 0.79 (m, 1H), 0.29 (t, *J* = 4.3 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.7, 97.9, 51.5, 43.3, 30.7, 26.9, 21.68, 21.66, 20.9, 20.8.

FTIR (NaCl, thin film, cm^{-1}): 2958, 2870, 1602, 1453, 1366, 1056, 973, 867, 832, 796, 754.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{15}Br$ $[M+\cdot]^+$: 214.0357; found: 214.0358.

(1*S*,4*R*,5*R*)-3-bromo-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-ene (50)



Prepared from (1*S*,4*R*,5*R*)-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-en-3-yl trifluoromethanesulfonate (85.3 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B with the exception that DMAP (0.03 mmol, 3.7 mg) was used in place of cod. The crude residue was purified by column chromatography (silica, pentane) to yield (51 mg, 78% yield) as a colorless oil.

Note: This compound is volatile.

$\mathbf{R}_f$ = 0.88 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = –13° (c = 0.5, $CHCl_3$).

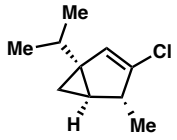
^{1}H NMR (500 MHz, $CDCl_3$): δ 5.93 (t, *J* = 1.3 Hz, 1H), 2.62 – 2.51 (m, 1H), 1.45 – 1.34 (m, 1H), 1.15 – 1.10 (m, 4H), 1.00 (d, *J* = 6.8 Hz, 3H), 0.90 (d, *J* = 6.8 Hz, 3H), 0.83 – 0.78 (m, 1H), 0.29 (t, *J* = 4.2 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 134.0, 124.0, 48.5, 40.9, 31.0, 26.5, 21.5, 20.9, 20.79, 20.77.

FTIR (NaCl, thin film, cm^{-1}): 2958, 2870, 1602, 1453, 1366, 1056, 973, 867, 832, 796, 754.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{15}Br$ $[M+\cdot]^+$: 214.0357; found: 214.0358.

(1*S*,4*R*,5*R*)-3-chloro-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-ene (51)



Prepared from (1*S*,4*R*,5*R*)-1-isopropyl-4-methylbicyclo[3.1.0]hex-2-en-3-yl trifluoromethanesulfonate (85.3 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B with the exception that DMAP (0.03 mmol, 3.7 mg) was used in place of cod. The crude residue was purified by column chromatography (silica, pentane) to yield (39 mg, 75% yield) as a colorless oil.

Note: This compound is volatile.

$\mathbf{R}_f$ = 0.85 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{\alpha}]_D^{25}$ = +17° (c = 1.0, $CHCl_3$).

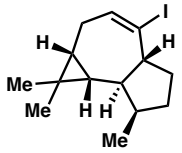
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.75 (t, *J* = 1.3 Hz, 1H), 2.56 – 2.46 (m, 1H), 1.37 (p, *J* = 6.8 Hz, 1H), 1.14 (d, *J* = 7.0 Hz, 3H), 1.10 (ddt, *J* = 7.9, 4.1, 0.9 Hz, 1H), 0.99 (d, *J* = 6.8 Hz, 3H), 0.89 (d, *J* = 6.8 Hz, 3H), 0.78 (dd, *J* = 7.8, 4.3 Hz, 1H), 0.27 (t, *J* = 4.2 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 134.6, 129.4, 46.8, 39.5, 31.1, 26.1, 21.6, 20.9, 20.8, 20.2.

FTIR (NaCl, thin film, cm^{-1}): 2956, 2924, 2854, 1458, 1364, 1057, 1026.

HRMS (EI, *m/z*): calc'd for $C_{10}H_{15}Cl$ $[M+\cdot]^+$: 170.0862; found: 170.0888.

(1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-4-iodo-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulene (52)



Prepared from (1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulen-4-yl trifluoromethanesulfonate (101.5 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (87.4 mg, 92% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (92 x 0.97 = 89% yield).

R_f = 0.72 (silica, hexanes, $KMnO_4$).

$[\boldsymbol{a}]_D^{25}$ = –184° (c = 1.0, $CHCl_3$).

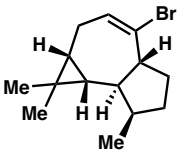
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.43 (ddd, *J* = 8.8, 3.7, 2.3 Hz, 1H), 2.77 (dddd, *J* = 14.2, 11.2, 7.4, 3.2 Hz, 1H), 2.36 – 2.23 (m, 1H), 2.18 – 1.98 (m, 3H), 1.89 (dddd, *J* = 13.1, 9.9, 8.2, 3.1 Hz, 1H), 1.77 (td, *J* = 11.7, 8.4 Hz, 1H), 1.44 (dddd, *J* = 12.5, 11.5, 9.8, 8.8 Hz, 1H), 1.16 (dtd, *J* = 13.1, 8.7, 4.5 Hz, 1H), 1.03 (s, 3H), 1.02 (s, 3H), 0.97 – 0.88 (m, 4H), 0.60 (dd, *J* = 11.5, 9.3 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 138.5, 109.1, 56.7, 43.5, 36.6, 36.3, 30.9, 28.7, 26.8, 26.2, 25.8, 19.3, 18.3, 15.3.

FTIR (NaCl, thin film, cm^{-1}): 2953, 2866, 1455, 1376, 1216, 909, 723.

HRMS (FAB, *m/z*): calc'd for $C_{14}H_{21}I$ $[M+H-H_2]^+$: 315.0610; found: 315.0609.

(1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-4-bromo-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulene (53)



Prepared from (1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulen-4-yl trifluoromethanesulfonate (101.5 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (75 mg, 93% yield) as a colorless oil.

$\mathbf{R}_f$ = 0.68 (silica, hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –152° (c = 1.0, $CHCl_3$).

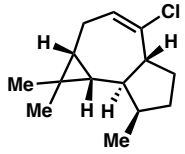
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.11 (ddd, *J* = 9.3, 3.3, 2.1 Hz, 1H), 2.77 (tddd, *J* = 11.4, 6.6, 3.8, 2.2 Hz, 1H), 2.30 – 2.10 (m, 3H), 2.05 – 1.85 (m, 2H), 1.76 (td, *J* = 11.7, 8.3 Hz, 1H), 1.46 (dddd, *J* = 11.4, 10.7, 9.8, 8.8 Hz, 1H), 1.18 (dtd, *J* = 13.1, 8.6, 4.3 Hz, 1H), 1.04 (s, 3H), 1.03 (s, 3H), 0.97 – 0.88 (m, 4H), 0.60 (dd, *J* = 11.5, 9.3 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 130.9, 129.9, 53.8, 43.6, 35.5, 33.7, 31.3, 28.7, 26.1, 25.7, 24.5, 19.0, 18.2, 15.3.

FTIR (NaCl, thin film, cm^{-1}): 2953, 2867, 1633, 1455, 1376, 1251, 1064, 913, 860, 732.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{14}H_{21}Br$ $[M+H–H_2]^+$: 267.0748; found: 267.0737.

(1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-4-chloro-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulene (54)



Prepared from (1a*R*,4a*R*,7*R*,7a*S*,7b*S*)-1,1,7-trimethyl-1a,2,4a,5,6,7,7a,7b-octahydro-1*H*-cyclopropa[*e*]azulen-4-yl trifluoromethanesulfonate (101.5 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (64 mg, 95% yield) as a colorless oil.

R_f = 0.78 (silica, hexanes, $KMnO_4$).

$[\alpha]_D^{25}$ = –174° (c = 1.0, $CHCl_3$).

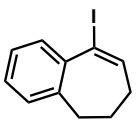
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.84 (ddd, *J* = 9.3, 3.3, 2.1 Hz, 1H), 2.77 – 2.60 (m, 1H), 2.27 – 2.08 (m, 3H), 2.01 (ddt, *J* = 16.8, 10.4, 3.6 Hz, 1H), 1.90 (dddd, *J* = 13.1, 9.9, 8.2, 3.1 Hz, 1H), 1.75 (td, *J* = 11.7, 8.3 Hz, 1H), 1.44 (dddd, *J* = 12.6, 11.3, 9.9, 8.8 Hz, 1H), 1.19 (dtd, *J* = 13.0, 8.6, 4.3 Hz, 1H), 1.04 (s, 3H), 1.03 (s, 3H), 0.95 – 0.86 (m, 4H), 0.60 (dd, *J* = 11.4, 9.3 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 138.6, 125.6, 51.9, 43.2, 35.0, 32.1, 31.6, 28.7, 26.1, 25.8, 23.0, 18.8, 18.1, 15.3.

FTIR (NaCl, thin film, cm^{-1}): 2952, 2866, 1453, 1376, 921, 748.

HRMS (EI, *m/z*): calc'd for $C_{14}H_{21}Cl$ $[M+\cdot]^+$: 224.1332; found: 224.1306.

9-iodo-6,7-dihydro-5*H*-benzo[7]annulene (55)



Prepared from 6,7-dihydro-5*H*-benzo[7]annulen-9-yl trifluoromethanesulfonate (87.7 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, hexanes) to yield (76.4 mg, 93% yield) as a light yellow oil. The purity was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (93 x 0.96 = 90% yield).

R_f = 0.66 (silica, hexanes, $KMnO_4$).

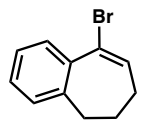
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.32 – 7.23 (m, 1H), 7.18 (td, *J* = 7.4, 1.4 Hz, 1H), 7.12 (dd, *J* = 7.4, 1.5 Hz, 1H), 6.95 (t, *J* = 7.5 Hz, 1H), 2.66 (t, *J* = 7.0 Hz, 2H), 2.14 (p, *J* = 7.1 Hz, 2H), 1.83 (q, *J* = 7.3 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 142.1, 141.3, 139.8, 131.1, 128.5, 128.2, 126.4, 95.8, 34.8, 32.6, 28.2.

FTIR (NaCl, thin film, cm^{-1}): 2928, 2854, 1478, 1447, 1195, 887, 763, 742, 662.

HRMS (FAB, *m/z*): calc'd for $C_{11}H_{11}I$ $[M+\cdot]^+$: 269.9906; found: 269.9910.

9-bromo-6,7-dihydro-5*H*-benzo[7]annulene (56)



Prepared from 6,7-dihydro-5*H*-benzo[7]annulen-9-yl trifluoromethanesulfonate (87.7 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, hexanes) to yield (65 mg, 95% yield) as a light yellow oil. The purity was determined by ^{1}H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (95 x 0.97 = 92% yield).

R_f = 0.51 (silica, hexanes, $KMnO_4$).

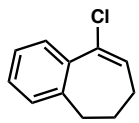
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.56 (dd, *J* = 7.7, 1.4 Hz, 1H), 7.29 (td, *J* = 7.5, 1.6 Hz, 1H), 7.22 (td, *J* = 7.3, 1.4 Hz, 1H), 7.19 – 7.15 (m, 1H), 6.64 (t, *J* = 7.3 Hz, 1H), 2.68 (t, *J* = 6.9 Hz, 2H), 2.19 – 2.08 (m, 2H), 1.95 – 1.88 (m, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 140.8, 138.9, 133.3, 129.5, 128.7, 128.5, 126.4, 120.7, 34.3, 32.7, 26.9.

FTIR (NaCl, thin film, cm^{-1}): 3062, 2930, 2856, 1614, 1480, 1448, 1303, 1197, 897, 765, 745, 668.

HRMS (EI, *m/z*): calc'd for $C_{11}H_{11}Br$ $[M+\cdot]^+$: 222.0044; found: 222.0042.

9-chloro-6,7-dihydro-5*H*-benzo[7]annulene (57)



Prepared from 6,7-dihydro-5*H*-benzo[7]annulen-9-yl trifluoromethanesulfonate (87.7 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, hexanes) to yield (54 mg, 91% yield) as a light yellow oil. The purity was determined by ^{1}H NMR to be 97% pure by mass (3% protodetriflation). The yield is adjusted accordingly (91 x 0.97 = 88% yield).

R_f = 0.54 (silica, hexanes, $KMnO_4$).

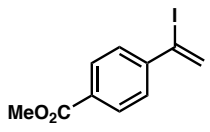
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.59 (dd, *J* = 7.6, 1.5 Hz, 1H), 7.30 (td, *J* = 7.5, 1.7 Hz, 1H), 7.26 – 7.22 (m, 1H), 7.22 – 7.18 (m, 1H), 6.39 (t, *J* = 7.1 Hz, 1H), 2.68 (t, *J* = 6.7 Hz, 2H), 2.17 – 2.08 (m, 2H), 1.98 (qd, *J* = 7.1, 0.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 141.1, 137.6, 130.7, 129.1, 128.9, 128.5, 128.3, 126.4, 33.8, 32.9, 26.1.

FTIR (NaCl, thin film, cm^{-1}): 3059, 2934, 2858, 1620, 1483, 1449, 1322, 1304, 1201, 1169, 916, 830, 766, 748, 676.

HRMS (EI, *m/z*): calc'd for $C_{11}H_{11}Cl$ $[M+\cdot]^+$: 178.0549; found: 178.0547.

methyl 4-(1-iodovinyl)benzoate (58)



Prepared from methyl 4-(1-(((trifluoromethyl)sulfonyl)oxy)vinyl)benzoate (93.1 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 5 to 20% Et_2O/hexanes) to yield (56 mg, 64% yield) as a white solid. *Note: This compound slowly oxidizes to the α-iodo acetophenone under ambient conditions.*[12]

R_f = 0.25 (silica, 10% Et_2O/hexanes, UV).

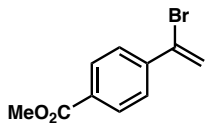
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.99 – 7.95 (m, 2H), 7.59 – 7.54 (m, 2H), 6.56 (d, *J* = 1.9 Hz, 1H), 6.17 (d, *J* = 1.9 Hz, 1H), 3.92 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 166.5, 145.8, 130.4, 129.6, 129.2, 128.2, 105.8, 52.4.

FTIR (NaCl, thin film, cm^{-1}): 2948, 1720, 1593, 1433, 1403, 1284, 1191, 1111, 1050, 902, 861, 777, 710.

HRMS (FAB, *m/z*): calc'd for $C_{10}H_8IO_2$ $[M+H]^+$: 288.9726; found: 288.9740.

methyl 4-(1-bromovinyl)benzoate (59)



Prepared from methyl 4-(1-(((trifluoromethyl)sulfonyl)oxy)vinyl)benzoate (93.1 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 1 to 2% Et_2O/hexanes) to yield (69 mg, 90% yield) as a white solid. *Note: This compound slowly oxidizes to the α-bromo acetophenone under ambient conditions.*[12]

R_f = 0.47 (silica, 10% EtOAc/hexanes, $KMnO_4$).

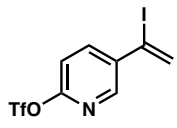
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.03 – 7.98 (m, 2H), 7.68 – 7.62 (m, 2H), 6.22 (d, *J* = 2.2 Hz, 1H), 5.88 (d, *J* = 2.2 Hz, 1H), 3.92 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 166.5, 142.7, 130.6, 129.9, 129.7, 127.4, 119.7, 52.4.

FTIR (NaCl, thin film, cm^{-1}): 3429, 2952, 1727, 1606, 1436, 1406, 1281, 1191, 1110, 1016, 860, 776, 710.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{10}H_8BrO_2$ $[M+H]^+$: 240.9864; found: 240.9888.

5-(1-iodovinyl)pyridin-2-yl trifluoromethanesulfonate (60)



Prepared from 1-(6-(((trifluoromethyl)sulfonyl)oxy)pyridin-3-yl)vinyl trifluoromethanesulfonate (120 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield **(**62 mg, 54% yield) as a colorless oil. *Note: This compound slowly oxidizes to the α-iodo acetophenone under ambient conditions.*[12]

R_f = 0.74 (silica, 30% EtOAc/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.51 (dd, *J* = 2.6, 0.7 Hz, 1H), 8.00 (dd, *J* = 8.5, 2.6 Hz, 1H), 7.13 (dd, *J* = 8.5, 0.7 Hz, 1H), 6.58 (d, *J* = 2.2 Hz, 1H), 6.25 (d, *J* = 2.1 Hz, 1H).

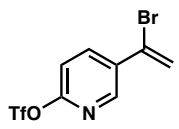
^{13}C NMR (101 MHz, $CDCl_3$): δ 155.6, 147.0, 141.0, 138.6, 130.9, 118.7 (q, J_{C-F} = 320.6 Hz), 114.6, 99.3.

^{19}F NMR (282 MHz, $CDCl_3$): δ -72.9.

FTIR (NaCl, thin film, cm^{-1}): 1604, 1579, 1469, 1428, 1370, 1215, 1171, 1137, 1020, 891, 842, 717, 647.

HRMS (TOF-ESI, *m/z*): calc'd for $C_8H_5F_3INO_3S$ $[M+H]^+$: 379.9065; found: 379.9076.

5-(1-bromovinyl)pyridin-2-yl trifluoromethanesulfonate (61)



Prepared from 1-(6-(((trifluoromethyl)sulfonyl)oxy)pyridin-3-yl)vinyl trifluoromethanesulfonate (120 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 10% Et_2O/hexanes) to yield (80 mg, 80% yield) as a colorless oil. *Note: This compound slowly oxidizes to the α-bromo acetophenone under ambient conditions.*[12]

R_f = 0.70 (silica, 30% EtOAc/hexanes, UV).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.58 (dd, *J* = 2.6, 0.7 Hz, 1H), 8.08 (dd, *J* = 8.5, 2.6 Hz, 1H), 7.18 (dd, *J* = 8.5, 0.6 Hz, 1H), 6.24 (d, *J* = 2.6 Hz, 1H), 5.96 (d, *J* = 2.6 Hz, 1H).

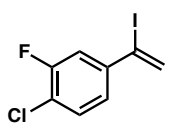
^{13}C NMR (126 MHz, $CDCl_3$): δ 155.8, 146.9, 140.1, 135.5, 124.9, 121.3, 118.7 (q, J_{C-F} = 320.7 Hz), 114.7.

^{19}F NMR (282 MHz, $CDCl_3$): δ -72.9.

FTIR (NaCl, thin film, cm^{-1}): 3105, 1615, 1582, 1470, 1426, 1370, 1215, 1173, 1137, 1020, 891, 621.

HRMS (TOF-ESI, *m/z*): calc'd for $C_8H_5F_3BrNO_3S$ $[M+H]^+$: 331.9204; found: 331.9195.

1-chloro-2-fluoro-4-(1-iodovinyl)benzene (62)



Prepared from 1-(4-chloro-3-fluorophenyl)vinyl trifluoromethanesulfonate (91.4 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica,

pentane) to yield (58 mg, 69% yield) as a yellow oil. *Note: This compound slowly oxidizes to the α-iodo acetophenone derivative under ambient conditions.*[12]

R_f = 0.57 (silica, hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.31 – 7.23 (m, 2H), 7.21 – 7.16 (m, 1H), 6.43 (d, *J* = 2.0 Hz, 1H), 6.06 (d, *J* = 2.0 Hz, 1H).

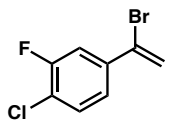
^{13}C NMR (101 MHz, $CDCl_3$): δ 157.5 (d, J_{C-F} = 249.4 Hz), 142.3 (d, J_{C-F} = 6.9 Hz), 130.3, 128.9, 124.4 (d, J_{C-F} = 3.5 Hz), 121.6 (d, J_{C-F} = 17.9 Hz), 116.5 (d, J_{C-F} = 22.8 Hz), 104.0 (d, J_{C-F} = 2.2 Hz).

^{19}F NMR (282 MHz, $CDCl_3$): δ -114.9 (dd, J_{F-H} = 10.1, 7.4 Hz).

FTIR (NaCl, thin film, cm^{-1}): 1598, 1484, 1414, 1402, 1285, 1244, 1070, 937, 901, 873, 818, 743, 733.

HRMS (EI, *m/z*): calc'd for C_8H_5ClFI $[M+\cdot]^+$: 281.9109; found: 281.9124.

1-bromo-2-fluoro-4-(1-iodovinyl)benzene (63)



Prepared from 1-(4-chloro-3-fluorophenyl)vinyl trifluoromethanesulfonate (91.4 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, pentane) to yield (52 mg, 73% yield) as a yellow oil. *Note: This compound slowly oxidizes to the α-bromo acetophenone derivative under ambient conditions.*[12]

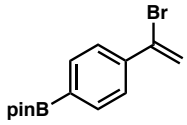
R_f = 0.65 (silica, hexanes, UV).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.41 – 7.35 (m, 2H), 7.32 (ddd, *J* = 8.4, 2.1, 0.7 Hz, 1H), 6.15 (d, *J* = 2.3 Hz, 1H), 5.83 (d, *J* = 2.3 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 157.6 (d, J_{C-F} = 249.1 Hz), 139.0 (d, J_{C-F} = 7.2 Hz), 130.3, 128.2 (d, J_{C-F} = 2.3 Hz), 123.5 (d, J_{C-F} = 3.8 Hz), 121.7 (d, J_{C-F} = 18.0 Hz), 119.2, 115.7 (d, J_{C-F} = 23.0 Hz).

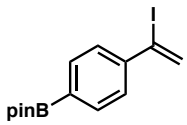
^{19}F NMR (282 MHz, $CDCl_3$): δ -114.8 (m).

FTIR (NaCl, thin film, cm^{-1}): 1601, 1570, 1485, 1412, 1289, 1246, 1174, 1066, 937, 892, 875, 819, 738.



HRMS (EI, *m/z*): calc'd for C_8H_5ClFBr $[M+\cdot]^+$: 233.9247; found: 233.9228.

2-(4-(1-iodovinyl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (64)



Prepared from 1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)vinyl trifluoromethanesulfonate (113.5 mg, 0.3 mmol) and sodium iodide (68 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 0 to 5% Et_2O/hexanes) to yield (72 mg, 68% yield) as a light yellow oil.

R_f = 0.53 (silica, 10% EtOAc/hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 – 7.72 (m, 2H), 7.53 – 7.48 (m, 2H), 6.51 (d, *J* = 1.8 Hz, 1H), 6.11 (d, *J* = 1.7 Hz, 1H), 1.34 (s, 12H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 144.3, 134.8, 128.0, 127.5, 107.5, 84.1, 25.0. *(Note: carbon bonded to boron not observed.)*

FTIR (NaCl, thin film, cm^{-1}): 2978, 2930, 1607, 1398, 1360, 1324, 1269, 1210, 1144, 1092, 1018, 859, 841, 654.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{14}H_{18}BIO_2$ $[M+H]^+$: 357.0523; found: 357.0527.

2-(4-(1-bromovinyl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (65)

Prepared from 1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)vinyl trifluoromethanesulfonate (113.5 mg, 0.3 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method C, Procedure 1. The crude residue was purified by column chromatography (silica, 0 to 5% Et_2O/hexanes) to yield (59 mg, 64% yield) as a light yellow oil which crystallized upon standing in the freezer.

R_f = 0.48 (silica, 10% Et_2O/hexanes, $KMnO_4$).

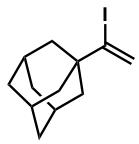
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 – 7.76 (m, 2H), 7.62 – 7.56 (m, 2H), 6.17 (d, *J* = 2.0 Hz, 1H), 5.81 (d, *J* = 2.0 Hz, 1H), 1.35 (s, 12H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 141.0, 134.8, 131.1, 126.6, 118.5, 84.1, 25.0. *(Note: carbon bonded to boron not observed.)*

FTIR (NaCl, thin film, cm^{-1}): 2979, 1607, 1507, 160, 1326, 1270, 1216, 1143, 1092, 1018, 859, 783, 656.

HRMS (TOF-ESI, *m/z*): calc'd for $C_{14}H_{18}BBrO_2$ $[M+H]^+$: 309.0661; found: 309.0670.

(3*r*,5*r*,7*r*)-1-(1-iodovinyl)adamantane (66)



Prepared from 1-((3*r*,5*r*,7*r*)-adamantan-1-yl)vinyl trifluoromethanesulfonate (93.0 mg, 0.3 mmol) and sodium iodide (67.5 mg, 0.45 mmol) according to Method A. The crude residue was purified by column chromatography (silica, pentane) to yield (76.5 mg, 88% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (88 x 0.98 = 86% yield).

R_f = 0.74 (silica, hexanes, $KMnO_4$).

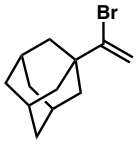
^{1}H NMR (400 MHz, $CDCl_3$): δ 6.08 (d, *J* = 2.1 Hz, 1H), 5.80 (d, *J* = 2.0 Hz, 1H), 2.00 (p, *J* = 3.3 Hz, 3H), 1.72 (d, *J* = 3.0 Hz, 6H), 1.71 – 1.59 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 131.8, 122.8, 42.4, 41.8, 36.8, 28.7.

FTIR (NaCl, thin film, cm^{-1}): 2903, 2849, 1611, 1600, 1450, 1343, 1257, 1184, 1142, 1055, 894, 612.

HRMS (FAB, *m/z*): calc'd for $C_{12}H_{17}I$ $[M+H]^+$: 289.0454; found: 289.0447.

(3*r*,5*r*,7*r*)-1-(1-bromovinyl)adamantane (67)



Prepared from 1-((3*r*,5*r*,7*r*)-adamantan-1-yl)vinyl trifluoromethanesulfonate (125 mg, 0.4 mmol) and lithium bromide (39.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield

(65.3 mg, 90% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 98% pure by mass (2% protodetriflation). The yield is adjusted accordingly (90 x 0.98 = 88% yield).

R_f = 0.81 (silica, hexanes, $KMnO_4$).

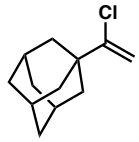
^{1}H NMR (400 MHz, $CDCl_3$): δ 5.56 (d, *J* = 2.1 Hz, 1H), 5.42 (d, *J* = 2.1 Hz, 1H), 2.03 (dd, *J* = 4.4, 2.2 Hz, 3H), 1.82 – 1.75 (m, 6H), 1.75 – 1.60 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 148.1, 113.7, 41.4, 41.1, 36.7, 28.5.

FTIR (NaCl, thin film, cm^{-1}): 2905, 2850, 2678, 1622, 1453, 1344, 1152, 1057, 881, 716, 628.

HRMS (EI, *m/z*): calc'd for $C_{12}H_{17}Br$ $[M+\cdot]^+$: 240.0514; found: 240.0510.

(3*r*,5*r*,7*r*)-1-(1-chlorovinyl)adamantane (68)



Prepared from 1-((3*r*,5*r*,7*r*)-adamantan-1-yl)vinyl trifluoromethanesulfonate (93.0 mg, 0.3 mmol) and lithium chloride (19.1 mg, 0.45 mmol) according to Method B. The crude residue was purified by column chromatography (silica, pentane) to yield (50.6 mg, 86% yield) as a colorless oil. The purity was determined by ^{1}H NMR to be 96% pure by mass (4% protodetriflation). The yield is adjusted accordingly (86 x 0.96 = 83% yield).

R_f = 0.84 (silica, hexanes, $KMnO_4$).

^{1}H NMR (400 MHz, $CDCl_3$): δ 5.13 (d, *J* = 1.5 Hz, 1H), 5.09 (d, *J* = 1.5 Hz, 1H), 2.04 (p, *J* = 3.1 Hz, 3H), 1.79 (d, *J* = 3.0 Hz, 6H), 1.76 – 1.62 (m, 6H).

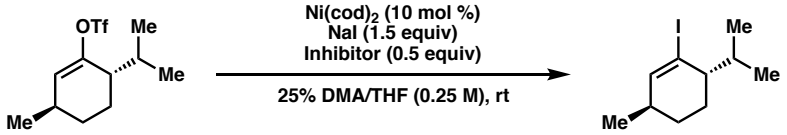
^{13}C NMR (101 MHz, $CDCl_3$): δ 153.5, 109.2, 40.7, 40.2, 36.7, 28.4.

FTIR (NaCl, thin film, cm^{-1}): 2904, 2851, 1618, 1452, 1344, 1165, 162, 877, 734, 666.

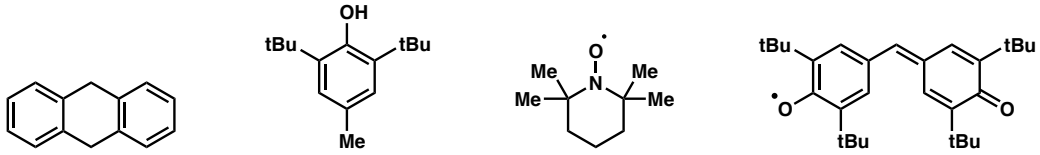
HRMS (EI, *m/z*): calc'd for $C_{12}H_{17}Cl$ $[M+\cdot]^+$: 196.1019; found: 196.1040.

5. Mechanistic Studies

a. Radical Inhibitors



Four 1-dram vials were equipped with stir bars and brought into a N_2-filled glovebox. The vials were charged with NaI (0.15 mmol, 1.5 equiv) and $Ni(cod)_2$ (2.8 mg, 0.01 mmol, 0.1 equiv). Anhydrous DMA (0.1 mL) and THF (0.3 mL) were added, resulting in a clear yellow solution. DHA, BHT, TEMPO and Galvinoxyl were each added to one vial (0.5 equiv), then enol triflate (0.1 mmol, 1 equiv) was added in one portion. The vials were sealed with a Teflon cap and brought out of the glovebox. The reactions were allowed to stir on the bench (480 rpm) for two hours at room temperature. Reactions were quenched by filtering through a plug of silica gel, eluting with 10 mL of 40% Et_2O/Hexanes, then concentrated under reduced pressure. An NMR standard (tetrachloronitrobenzene) was added to each vial for NMR analysis.



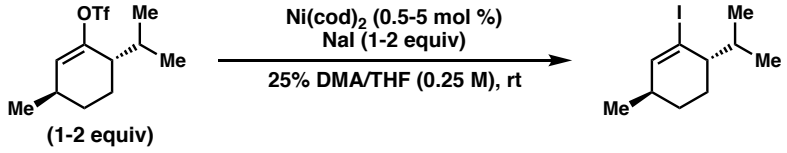
DHA
62% yield

BHT
67% yield

TEMPO
0% yield

Galvinoxyl
5% yield

b. Kinetics



A 2-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with NaI and $Ni(cod)_2$. Anhydrous DMA (0.5 mL) and THF (1.5 mL) were added. Undecane (32 μL) was added as an internal analytical GC standard. Alkenyl halide (0.5 mmol, 1 equiv) was added neat. The vial was sealed with a Teflon cap and allowed to stir in the glovebox (480 rpm) at room temperature. Reaction aliquots (50 μL) were taken at various time points and were quenched by addition into 1 mL hexanes in a GC vial, giving an opaque white mixture. The reaction aliquots were analyzed by GC-FID.

Effect of [Ni]:

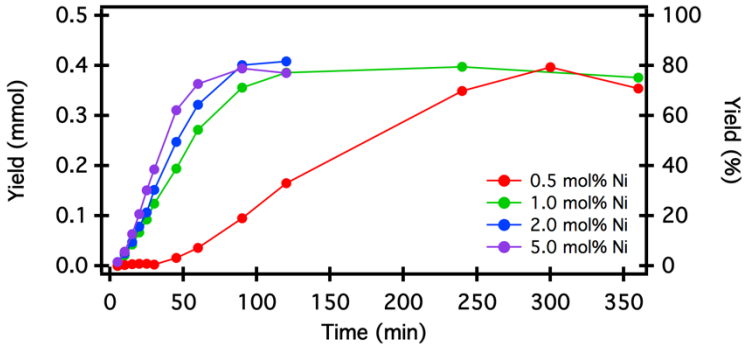


Figure S3: Yield of alkenyl halide **4a** with various loadings of $Ni(cod)_2$.

Effect of NaI concentration:

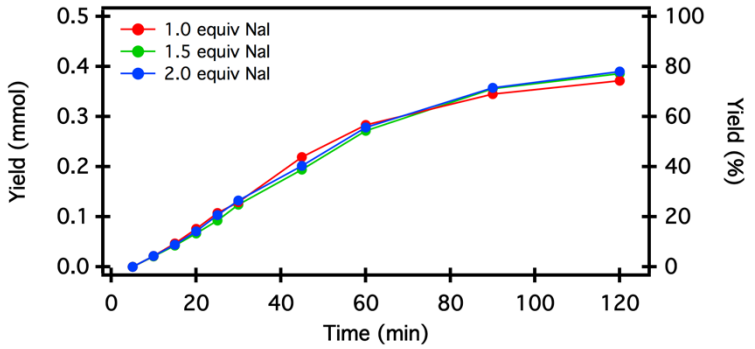


Figure S4: Yield of alkenyl halide **4a** with various loadings of NaI at 1 mol % Ni.

Effect of Enol Triflate Concentration:

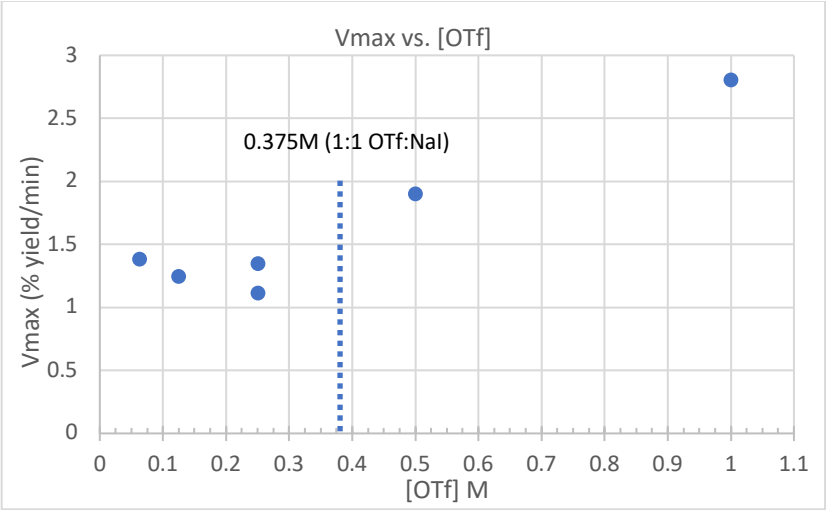


Figure S5: V_{max} vs. [OTf]. Run with 0.0025M $Ni(cod)_2$, 0.375M NaI. Vmax was calculated by fitting yield vs time data to an appropriate higher order polynomial followed by taking the derivative in Microsoft Excel.

Effect of cod:

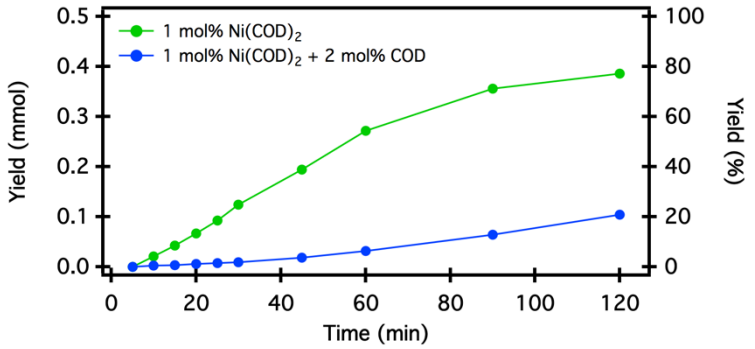


Figure S6: Yield of alkenyl halide **4a** with and without exogenous cod. The yield of **4a** was 80% after 14 hours.

Effect of Stir Rates:

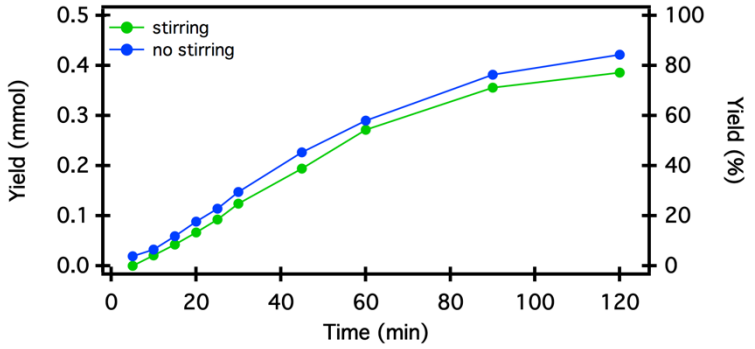


Figure S7: Yield of alkenyl halide **4a** with and without stirring the reaction at 1 mol % Ni.

Data Processing

Data from each run was converted from mmol to mM, then fit with a sigmoid fit in Igor Pro software. The respective fits were then plotted over the existing data points (**Figure S8**) and the derivative of the fit was calculated in Excel (**Figure S9**) to give the rate of the product formation as a function of time. The maximum rate was extracted from the respective plots and graphed as a function of [Ni] (**Figure S10**), which shows a positive dependence on Ni at lower [Ni] that deviates from first order at higher [Ni].

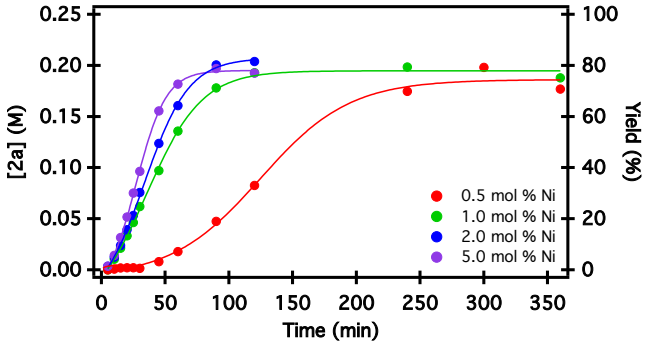


Figure S8: Yield of alkenyl halide **4a** at varying [Ni(cod)$_2$]. The reaction profiles are fitted with sigmoid fits and overlaid with the data points on the graph.

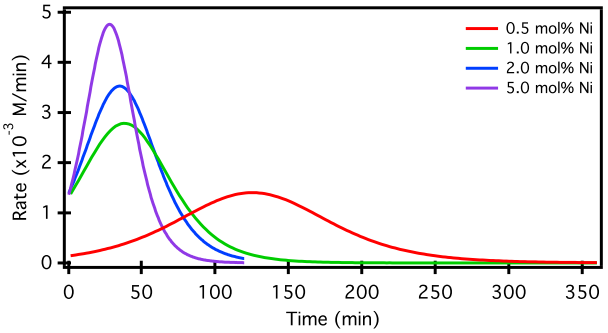


Figure S9: Derivatives of the sigmoid fits in give the rate of formation of **2a** as a function of time at varying [Ni].

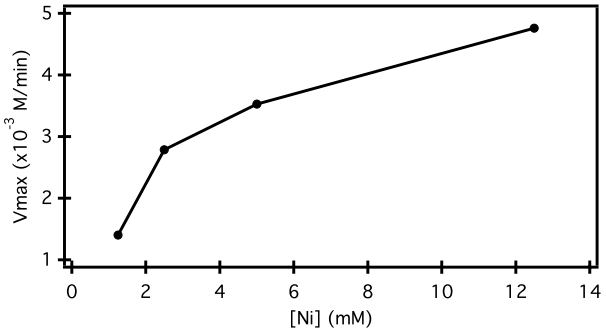
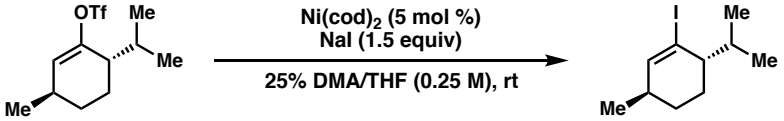


Figure S10: Maximum rate of formation of **4a** at varying [Ni(cod)$_2$].

c. EPR Studies



A 15 mL round-bottom flask equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with NaI (1.2 mmol, 1.5 equiv) and Ni(cod)$_2$ (11.2 mg, 0.04 mmol, 0.05 equiv). Anhydrous DMA (0.8 mL) and THF (2.4 mL) were added. Enol triflate (0.8 mmol, 1 equiv) was added neat. The flask was sealed with a septum and allowed to stir in the glovebox (480 rpm) at room temperature. Aliquots (0.3 mL) were removed at various time points and added into EPR tubes, which were sealed and frozen at –78 ºC in a metal dewar filled with liquid nitrogen. The reaction aliquots were analyzed by EPR spectroscopy. An external standard of $CuSO_4$ in 1:9 ethylene glycol/H_2O was made and analyzed by EPR spectroscopy.

A single Ni(I) species is visible by EPR spectroscopy, which reaches a maximum concentration at 30 minutes. An additional broad Ni(II) species also forms as the reaction proceeds, which may indicate aggregate Ni species. In order to remove contribution from the broad Ni(II) signal, baseline corrections were applied using the 'msbackadj' command in MatLab.

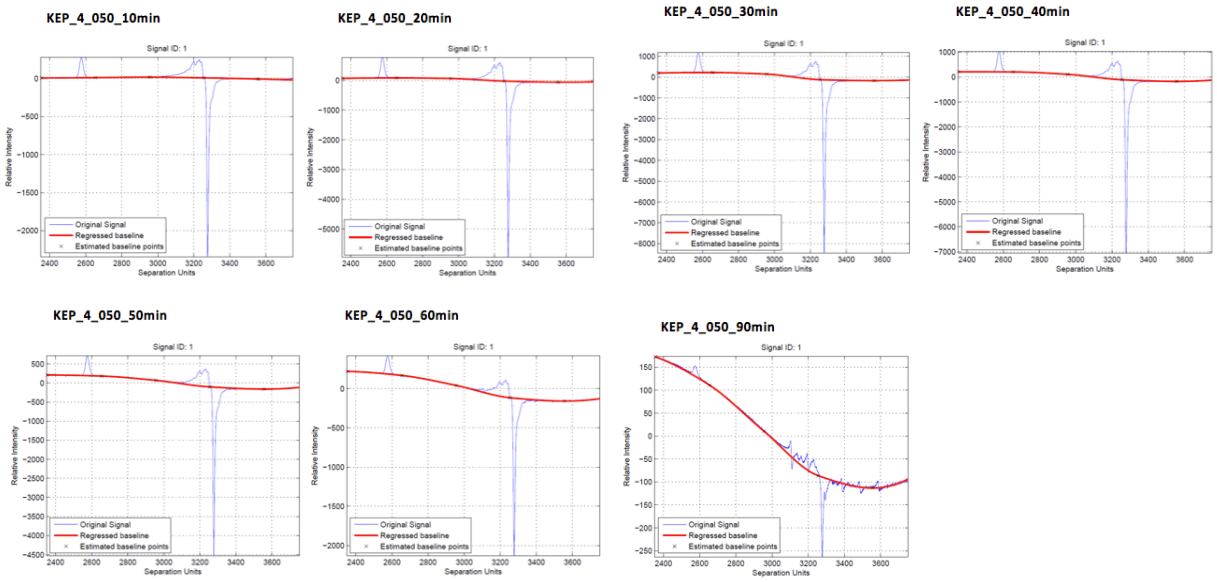


Figure S11: Baseline corrections of EPR spectra using MatLab.

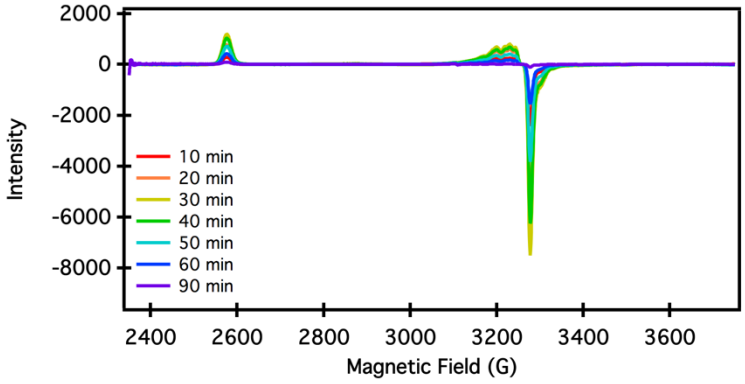


Figure S12: EPR spectra of the iodination of **3** at various time points.

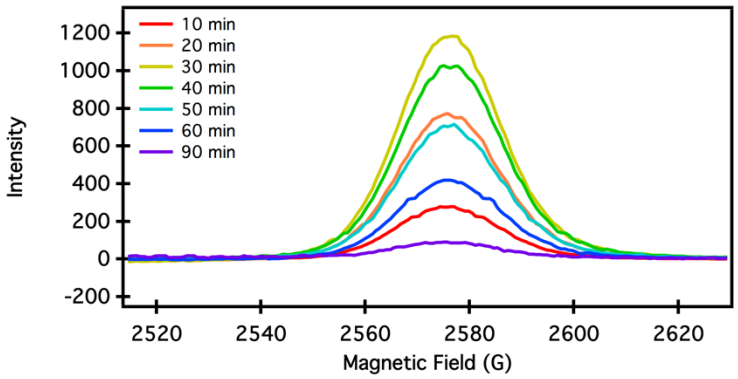


Figure S13: EPR spectra of the iodination of **3** at various time points (2520-2620 G region).

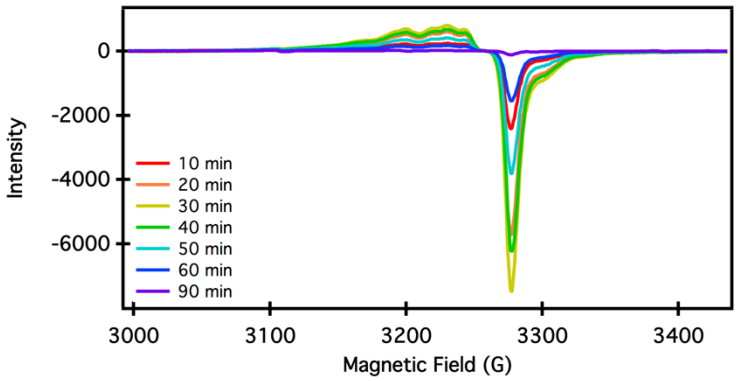


Figure S14: EPR spectra of the iodination of **3** at various time points (3000-3400 G region).

The spectra in **Figure S12** were processed by calculating the double integral. By comparison to the known concentration of $CuSO_4$ in **Figure S15**, the concentration of Ni(I) in the reaction was calculated to be <0.25 mM (i.e. less than 2% of all Ni added to the reaction, therefore indicating the Ni(I) species in this EPR spectrum is a trace Ni species).

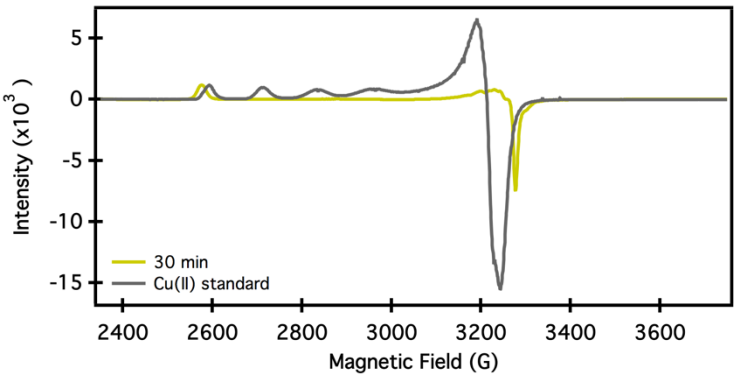


Figure S15: EPR spectra of the iodination of **3** at 30 minutes compared to 12.5 mM $CuSO_4$.

The halogenation of **1a** was repeated with LiBr and LiCl to investigate the bromination and chlorination reactions. Time points were taken at 30 minutes and analyzed by EPR spectroscopy, demonstrating that the Ni(I) species observed does contain a halogen atom. The relative intensities of the spectra are I > Br > Cl.

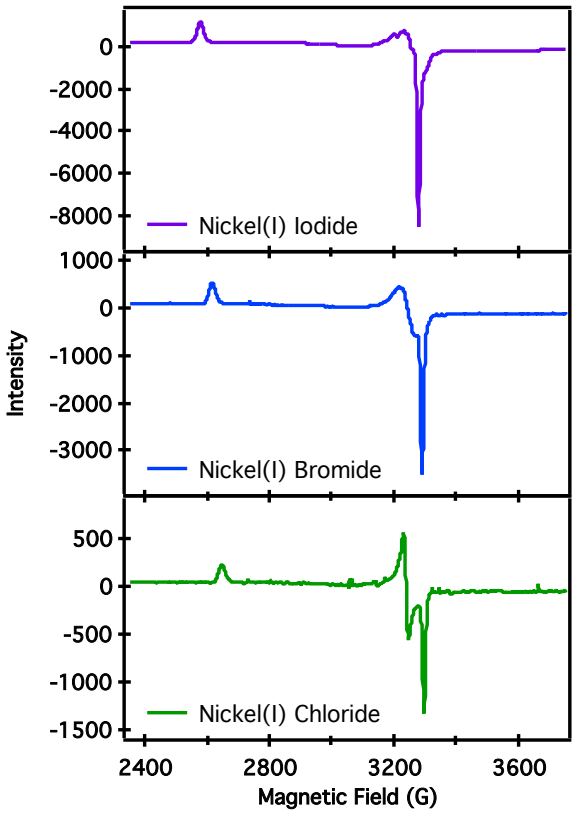
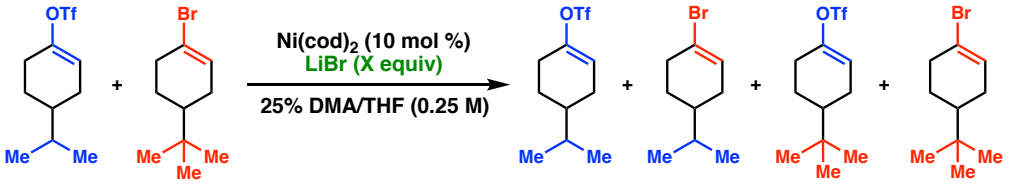


Figure S16: EPR spectra of the iodination, bromination, and chlorination of **3** at 30 minutes.

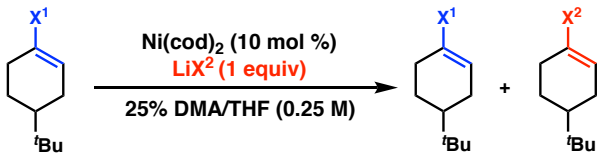
d. Crossover Experiments



0 equiv LiBr	100% recovered	0%	0%	100% recovered
0.1 equiv LiBr	90% recovered	10%	0%	100% recovered
1.0 equiv LiBr	0% recovered	90%	0%	100% recovered

A 2-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with LiBr (X equiv) and $Ni(cod)_2$ (5.5 mg, 0.02 mmol, 0.1 equiv). Anhydrous DMA (0.2 mL) and THF (0.6 mL) were added, resulting in a clear yellow solution. Undecane (13 µL) was added as an internal analytical GC standard. Enol triflate (0.2 mmol, 1 equiv) was added neat, followed by alkenyl bromide (0.2 mmol, 1 equiv). The vial was sealed with a Teflon cap and allowed to stir in the glovebox (480 rpm) at room temperature. Reaction aliquots (25 µL) were taken at time points and were quenched by addition into 1 mL hexanes in a GC vial, giving an opaque white mixture. The reaction aliquots were analyzed by GC-FID against the internal standard.

e. Halide Competition Experiments



A 2-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with LiX^2 (0.5 mmol, 1 equiv) and $Ni(cod)_2$ (13.8 mg, 0.05 mmol, 0.1 equiv). Anhydrous DMA (0.5 mL) and THF (1.5 mL) were added. Undecane (32 µL) was added as an internal analytical GC standard. Alkenyl halide (RX^1) (0.5 mmol, 1 equiv) was added neat. The vial was sealed with a Teflon cap and allowed to stir in the glovebox (480 rpm) at room temperature. Reaction aliquots (50 µL) were taken at time points and were quenched by addition into 1 mL hexanes in a GC vial,

giving an opaque white mixture. The reaction aliquots were analyzed by GC-FID against the internal standard.

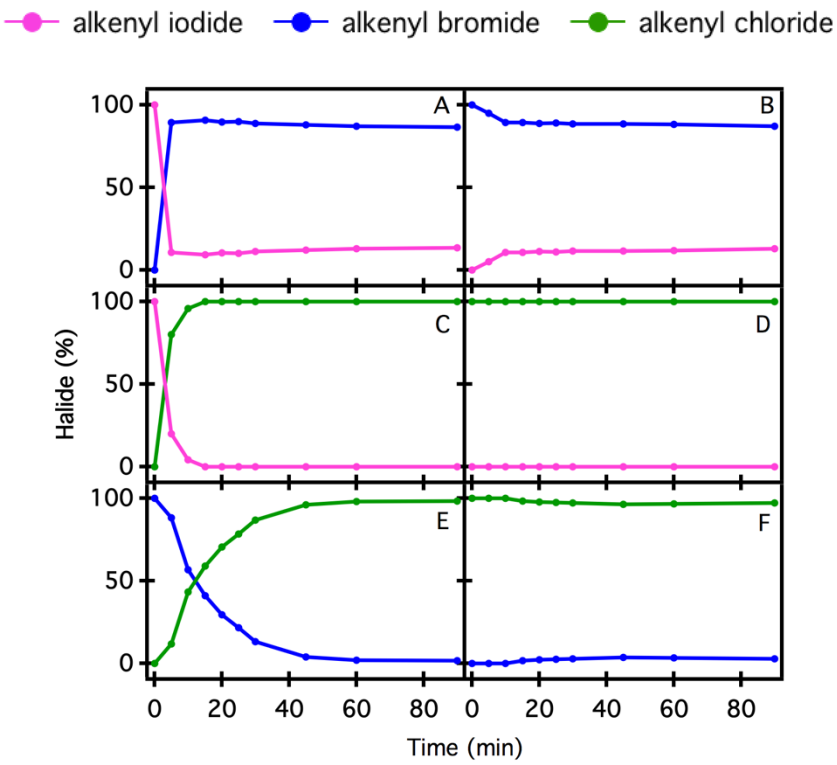


Figure S17: Ratios in terms of percentages for halide cross-over experiments: **A)** alkenyl iodide + LiBr, **B)** alkenyl bromide + LiI, **C)** alkenyl iodide + LiCl, **D)** alkenyl chloride + LiI, **E)** alkenyl bromide + LiCl, and **F)** alkenyl chloride + LiBr.

f. NMR Experiments on Oxidative Addition

A 1-dram vial equipped with a stir bar was brought into a N_2-filled glovebox. The vial was charged with $Ni(cod)_2$ (5.5 mg, 0.02 mmol, 1.0 equiv). Deuterated DMA (0.2 mL) and deuterated THF (0.6 mL) were added and solubilized, affording a yellow solution. Trimethoxybenzene was added as an internal analytical NMR standard. Enol triflate **3** (5.7 mg, 0.02 mmol, 1 equiv) was added neat and the reaction was stirred for 10 seconds, then the mixture was transferred to a J Young NMR tube. NMR analysis was performed at 10, 70 and 130 min against the internal standard. No oxidative addition of the enol triflate was observed, however cod dissociation from $Ni(cod)_2$ was observed over time via NMR concomitant with the reaction turning brown in color. See S302-S305 for NMR spectra.

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